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No. 14

EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

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EXPERIMENTAL STUDY OF EFFECTS OF INDUSTRIAL FREQUENCY ELECTROMAGNETIC FIELDS ON REPRODUCTIVE FUNCTION

Moscow GIGIYENA I SANITARIYA in Russian No 6, 1977 pp 22-25

[Article by L. G. Andriyenko, Kiev Scientific Research Institute of General and Municipal Hygiene imeni A. N. Marzeyev, submitted 6 Aug 76]

[Text] The objective of this work was to investigate reproductive function of albino rats exposed for a long time to industrial frequency electromagnetic fields (EMF) at a voltage of 5 kV/m. This voltage is considered the standard under industrial conditions for personnel servicing electric power lines and substations ("Labor Safety Standards and Rules"). The effect of industrial frequency on reproductive function was not taken into consideration in substantiating this standard.

Experiments were conducted on 500 mature, mongrel white rats (270 females and 230 males) weighing 150-170 g. The dynamics of our studies were as follows: for 4 weeks before the experiment, we observed the course of the females' estral cycle (we took females with established cycle in the experiment). We tested the effect of EMF on reproductive function of the animals 1.5, 3.5 and 4.5 months after the start of exposure to this factor and 1 month after termination thereof (to study recovery processes). At each of these times we mated experimental rats of one sex with intact animals of the other sex in a ratio of one male to three females. The females were put with males at the estrus or proestrus stage, and they were kept together until visible signs of pregnancy appeared, after which the females were kept separately and under observation until parturition. The capacity for fertilization (determined according to time between mating and parturition) and fertility (number of rats in litter, birth weight, number of stillbirths) served as indices of reproductive function of experimental rats of both sexes. We recorded the number of females that delivered litters, as well as those that died during or post partum, and developmental anomalies in the offspring and postnatal offspring deaths.

We examined the microstructure of the gonads of experimental rats in the course of the experiment. In addition, we assessed the effect of industrial frequency EMF on male reproductive function according to morphological and functional indices of spermatozoa (V. K. Milovanov). Determination was made of concentration of spermatozoa in a cell suspension prepared from the testes and appendages (L. V. Martson[!]), number of live and dead sperm, proportion of normal and atypical forms, functional activity of testicular mitochondria (state of oxidative phosphorylation--Yu. N. Leykin and A. D. Vinogradov).

The condition of spermatogenic epithelium, the stage of development of which was classified according to Leblond and Clermont, was evaluated according to the following quantitative indices: index of spermatogenesis (method of Fogg and Cowing), mean number of spermatogonia per canal (a count was made in 20 canals), number of canals with desquamated epithelium and at 12th stage of meiosis (the last 2 indices were expressed as percentages per 100 canals examined). In addition to the above general indices of reproductive function, in females we examined ovarian function by means of the vaginal test developed by Stockard and Papanicolau. We determined mean duration of cycle, mean number of cycles per female (per month) and mean number of normal cycles per female.

Prolonged exposure to EMF at industrial frequencies and voltage of 5 kV/m induced impairment of generative function in experimental rats of both sexes, with general preservation of reproductive capacity. The changes in reproductive function in common in males and females consisted of an increase in time required for fertilization, small size of offspring and lower viability thereof, as manifested by an increase in stillbirths and deaths prior to the 21st day of neonate development (see Table), and some developmental anomalies in the offspring.

The developmental anomalies were analogous in nature and severity in the offspring of experimental males and females. In addition to small size, the neonates born at different times in the course of the experiment presented hematomas, mainly in the region of the head and spine. There was retarded development of pelage, with uneven replacement of lanugo by fur and, against the background of fur, there were areas covered by lanugo that appeared bald. The neonates presented developmental defects of the front legs (both were bent in one baby rat and, as it developed, the animal moved without straightening the forelegs; in another one leg was shorter than the other and could not bend).

Impaired ovarian function was demonstrated in the females, as manifested by longer total duration of estral cycle, fewer cycles per female per month and a sharp decrease in number of normal cycles per female. The cycle changes were usually referable to a longer stage of rest.

Morphological examination of the reproductive system of experimental females revealed plethora (occasionally severe) of the uterus and ovaries (which could explain the isolated cases of hemorrhages in females during parturition). Against the background of impaired blood supply, trophic changes developed in the uterus and its stroma was somewhat thickened.

As related to the cycle disturbances, the demonstrated dystrophy of epithelial cells of secondary ovarian follicles, consolidation of the stroma and separation of cells of the granular layer from the basement membrane are indicative

Indices of generative function of albino rats exposed to industrial frequency EMF at 5 kV/m

Index	Statistical index	Time of study, months									1 month after termination of exper.		
		1½			3½			4½					
		control	experiment: M with intact F	experiment: F with intact M	control	experiment: M with intact F	experiment: F with intact M	control	experiment: M with intact F	experiment: F with intact M	control	experiment: M with intact F	experiment: F with intact M
Time after mating	$M \pm m$ P	25,7±0,09 —	27,5±0,09 >0,05	28,3±0,09 >0,05	26,8±3,47 —	27,45±3,17 >0,05	36,6±4,4 <0,05	27,6±1,40 —	46,2±4,30 <0,002	31,6±3,5 >0,05	27,7±2,40 —	35,8±2,70 <0,05	34,9±2,60 <0,05
Neonates: total*		115	117	148	123	81	98	120	88	85	129	99	75
live		115 (100%)	117 (100%)	148 (100%)	123 (100%)	81 (100%)	97 (97,5%)	120 (100%)	88 (97,8%)	81 (95,7%)	128 (93,3%)	95 (73,7%)	72 (96,0%)
stillborn		—	—	—	—	—	1 (2,5%)	—	2 (2,2%)	4 (4,3%)	1 (6,7%)	4 (26,6%)	3 (4,0%)
Mean rats per litter	$M \pm m$ P	8,21±0,48 —	8,45±0,49 >0,05	10,6±0,89 <0,02	8,20±0,59 —	7,36±6,0 >0,05	7,54±0,6 >0,05	8,0 —	8,0 —	7,7±1,1 >0,05	8,6±9,35 —	7,62±1,63 >0,05	7,5±0,9 >0,05
Mean neonate weight, g	$M \pm m$ P	6,25±0,21 —	6,08±0,24 >0,05	5,55±0,24 <0,05	6,6±0,16 —	5,7±0,15 <0,02	5,9±0,28 <0,05	6,7±0,16 —	5,65±0,23 <0,01	5,8±0,25 <0,01	6,66±0,1 —	6,1±0,18 <0,05	6,2±0,29 >0,01
Postnatal mortality,%	$M \pm m$ P	4,3±0,008 —	14,8±0,2 <0,01	12,9±0,9 <0,02	5,7±0,066 —	12±0,108 <0,01	12,0±4,8 >0,05	7,6±0,064 —	14,7±0,21 <0,01	12,0±1,6 <0,001	4,6±0,066 —	11,1±0,13 <0,01	13,3±0,26 <0,001

*Rats born to females that died during and after parturition were not counted. [M--males, F--females]

of ovarian dysfunction with an increased amount of follicle-stimulating hormone, which is inherent in aging reproductive glands (N. O. Melik-Alaverdyan).

The depression of reproductive capacity of males could be attributed to changes in functional and morphological indices of reproductive glands, which usually appeared after exposure to EMF for 3.5 months and progressed somewhat toward the end of the experiment. We observed a decrease in total number of spermatozoa, which became reliable after 3.5 months of the experiment (56.0±0.006 million/ml in the control and 40.0±0.002 million/ml in the experiment; $P<0.05$), an increase in percentage of dead spermatozoa (23.0±4.6 in the control and 46.4±4.7 in the experiment; $P<0.05$) and atypical forms of sperm (16.2±3.7 in the control and 39.1±5.55 in the experiment; $P<0.01$).

The above functional changes in spermatozoa were associated with impaired functional activity of testicular mitochondria, as manifested by depressed phosphorylating respiration and dissociation of respiration and phosphorylation in the mitochondria. The lesions we demonstrated in the respiratory chain of the mitochondria are referable, according to the classification of Daniel and Beadoin, to early disturbances of processes of oxidative phosphorylation of the ischemic type.

Examination of microstructure of male gonads revealed disorders referable to blood supply and, against this background, dystrophic and destructive changes causing lowering of morphological indices of the spermatogenic epithelium in the course of the experiment related to time and as compared to the control. The spermatogenesis index of experimental males dropped (with statistical reliability after exposure to EMF for 1.5 months: 3.52±0.02 in the control and 3.12±0.11 in the experiment; $P<0.02$); processes of desquamation of generative epithelium intensified in the testes (reliably, after 4.5 months 8% of the canals with desquamated epithelium were seen in the control and 22%, in the experiment; $P<0.05$) and there was a decrease in amount of spermatogonia (48.71±1.3 in the control and 40.58±2.5 in the experiment; $P<0.05$). We also observed an increase in number of immature forms of spermia in the course of the experiment.

In the aftereffect period (1 month after discontinuing exposure to EMF), there was gradual normalization of indices of generative function; however, they remained reliably altered, as compared to the control.

Conclusions

1. Industrial frequency EMF of 5 kV/m have an adverse effect on reproductive function of albino rats in the case of prolonged exposure; this is indicated by the small size of offspring, an increase in number of frail specimens and developmental anomalies in the baby rats.

2. The decreased reproductive capacity of the animals is due to impairment of structure of internal reproductive organs as a result of change in their morphological and functional indices due to the effects of EMF.

3. One of the causes of the deleterious effect of the factor under study on specific function of the organism is, perhaps, impaired blood flow [hyperemia] in the organism of experimental animals, which led to impairment of the respiratory chain in the testicular mitochondria.

4. The obtained data warrant raising the question of lowering the maximum permissible voltage of EMF in industry and developing a hygienic standard for the public residing in the area of action of EMF. Further research is required to resolve this problem definitively.

BIBLIOGRAPHY

1. Vinogradov, A. D. in "Mitokhondrii. Biokhimiya i Ul'trastruktura" [Mitochondria. Biochemistry and Ultrastructure], Moscow, 1973, pp 62-66.

2. Martson', L. V. "Comparative Study of the Effects of Some Dithiocarbamic Acid Derivative Pesticides on Embryonic Development and Reproductive Function of Animals," author abstract of candidatorial dissertation, Kiev, 1971.

3. Melik-Alaverdyan, N. O. "Generative Function of the Ovaries and Estral Cycle of Albino Rats With Chronic Chloroprene Poisoning," Yerevan, 1967.

4. Milovanov, V. K. "Biology of Reproduction and Artificial Insemination in Animals," Moscow, 1962.

5. Pudovkin, A. I. in "Nervnaya sistema" [The Nervous System], Leningrad, Vyp 5, 1964, pp 47-50.

6. "Normy i pravila po okhrane truda pri rabotakh na podstantsiyakh i vozdushnykh liniyakh elektroperedachi napryazheniyem 400, 500 i 750 kV peremennogo toka promyshlennoy chastoty" [Labor Safety Standards and Rules for Working at Substations and on Aerial Power Lines Carrying 400, 500 and 750 kV Alternating Current at Industrial Frequencies] Moscow, 1972.

7. Daniel, A., and Beadoin, J. J. SURG. RES., Vol 17, 1974, pp 19-25.

8. Leblond, C., and Clermont, J. AM. J. ANAT., Vol 90, 1952, pp 167-206.

9. Stockard, Q., and Papanicolau, J. Ibid, Vol 22, 1917, p 225.

10. Fogg, L. C., and Cowing, R. F. CANCER RES., Vol 2, 1951, pp 23-27.

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INFLUENCE OF AN ELECTRIC FIELD OF COMMERCIAL FREQUENCY AND DIFFERENT INTENSITY ON THE BALANCE AND METABOLISM OF COPPER, MOLYBDENUM AND IRON IN THE ORGANISMS OF LABORATORY ANIMALS

Kiev FIZIOLOGICHNYY ZHURNAL in Ukrainian No 3, 1977 pp 369-372

[Article by I. P. Kozyaryn, I. A. Mykhalyuk and L. D. Fesenko, Department of General Hygiene, Kiev Medical Institute]

[Text] As has been shown by numerous investigations of scientific associates of our department, the balance and interorganic metabolism of biological trace elements depend to a considerable degree on the influence on the organism of physical and chemical factors of the external environment [1-3, 5,6] and the functional state of the central nervous system [3]. It has been established [2] that disorders in the balance and interorganic metabolism of trace elements are one of the earliest signs of an unfavorable influence on the organism of ultra-high frequency energy [2].

We have studied changes of the balance and interorganic distribution of copper, molybdenum and iron under the influence on the organism of a commercial-frequency electric field (CFEF) with different intensities, since with growth of scientific and technical progress an ever-larger number of persons are experiencing the influence of that radiation under industrial and ordinary living conditions.

Procedure of the Investigations

The investigations were conducted on male white rats with an initial weight of 120.0 $\pm$ 5.0 g. Depending on the intensity of the CFEF, the animals were divided into groups of 25 rats each. The animals of the first group served as a control (were not irradiated), the field intensity was 1 kV/m on the second group (irradiated), 2 kV/m on the third, 4 kV/m on the fourth, 7 kV/m on the fifth and 15 kV/m on the sixth. The irradiation was conducted for 2 hours per day for 4 months, for which the animals were placed in dielectric cells with a model electric field with a frequency of 50 Hz, which was created by an NOM-10 transformer. The 2-hour exposure was selected because considerable groups of people experience the daily effect of a commercial-frequency electric field, as a rule, from 10-15 minutes to 2 hours per day under production and ordinary living conditions. At the end of the experiment the animals were decapitated.

The contents of copper, molybdenum and iron in the tissues were determined by a quantitative spectrographic method with an ISP-28 spectrograph. The tissues of the dead animals were dried in a desiccator at 105°C to a constant weight and concentrated in a muffle furnace at not over 500°C to avoid losses of portions of trace elements before the ash is obtained. The ash of each sample was burned in the ISP-28 spectrograph (in three parallel tests) to obtain spectrograms. Standards were burned simultaneously. The intensity of the blackening of lines was measured with a microthermometer (3274.0 Å for copper, 3170.34 Å for molybdenum and 2599.56 Å for iron). The trace element contents were designated in comparison with the standards with use of a logarithmic scale [4].

The results of the investigations were processed statistically. The results proved to be reliable at $p < 0.05$.

Results of the Investigations and Their Discussion

The results of the investigations showed that very reliable changes of inter-organic metabolism and the distribution of trace elements, as well as of other indicators (the functional state of the nervous system, working capacity and the state of protein and carbohydrate metabolism, etc) were observed in animals which had experienced the effect of CFEF with intensities of 7 and 15 kV/m.

It is evident from Table 1, in which data depicting the state of copper metabolism is presented, that in control animals copper is deposited mostly in the liver and bones (759.3±39.9 and 335.4±26.8 mkg% respectively). Then in decreasing order come the teeth, kidneys and myocardium, in which the copper content remains in the range of 100-240 mkg%; the spleen and brain contain from 58.4±3.5 to 65.6±2.6 mkg% Cu and, finally, in the skeletal muscles and skin the quantity of the trace element becomes only 11.5±0.6 and 19.5±1.2 mkg%.

The irregular distribution of trace elements except copper in the organs is connected with distinctive features of the blood supply of the organs and tissues and their microstructure and chemical composition, with peculiarities of metabolism intrinsic to the given tissue and with the presence of metalloenzymes and other biologically active metalloorganic compounds. In terms of absolute weight the copper content in all the organs and tissues of the control group as a whole was 198.8±9.9 mkg. The principal mass of the trace element is contained in the hard tissues (the teeth and bones) -- 93.8±7.5 mkg, then follows the liver (70.5±3.5 mkg) and the skeletal muscles (22.1±1.3 mkg). In other organs and tissues the absolute weight of the copper is from 5.4 to 0.6 mkg.

Analysis of the data of Table 1 shows that under the influence of CFEF the copper content increases in all the organs except the liver (the physiological storage place of trace elements), where the copper content decreases during a considerable increase in the executive organs. The copper content increases greatly in organs of blood supply: 170% in the spleen, 420% in the brain, 160% in the myocardium and 30% in the skin, and also in the hard tissues -- 140% in the bones and 270% in the teeth. Copper accumulation in the kidneys (220% increase) obviously is connected with their excretory function, as copper is excreted from the organism except for the intestines and with the urine.

Table 1 Copper content in tissues of the internal organs of white rats after four months of the effect of a commercial-frequency electric field (in mkg% of the moist weight of the organ or tissue)

	A Тканини	B Статистичні показники	C Групи тварин, напруженість поля, кВ/м					
			a 1 група	b 2 група	c 3 група	d 4 група	e 5 група	f 6 група
			1 контроль	2 1 кВ/м	3 2 кВ/м	4 4 кВ/м	5 7 кВ/м	6 15 кВ/м
a)	Печінка	$M \pm m$	759,3±39,9	603,0±42,2*	603,1±24,1*	389,4±19,5**	331,4±19,9**	288,7±14,4**
b)	Нирки	$M \pm m$	224,1±13,4	224,1±11,2	346,9±20,8**	380,4±15,2	537,4±37,6**	724,9±36,2**
c)	Селезінка	$M \pm m$	65,6±2,6	94,9±5,7**	94,9±4,7**	106,4±7,4**	108,9±7,6**	176,7±10,6**
d)	Головний мозок	$M \pm m$	58,4±3,5	61,2±4,3	64,1±4,5	193,5±9,7	260,9±10,4**	306,7±21,4**
e)	Серцевий м'яз	$M \pm m$	106,0±7,4	111,0±4,4	111,1±5,5	168,1±11,8**	221,6±11,1	278,9±11,1**
f)	Скелетні м'язи	$M \pm m$	19,5±1,2	21,4±1,7	30,9±2,2**	25,8±2,1*	25,5±0,6**	24,6±1,5*
g)	Шкіра	$M \pm м$	11,5±0,6	9,7±0,7	8,7±0,5**	13,5±0,7*	16,9±1,0**	19,5±0,8**
h)	Кістки (стегнові)	$M \pm m$	335,4±26,8	376,4±22,6	496,2±19,8**	496,2±37,7**	624,6±43,7**	823,5±41,2**
i)	Зуби (різці)	$M \pm m$	237,8±16,6	285,9±14,3	285,9±17,1	611,6±36,7**	806,1±32,2**	883,7±53,0

* — $p < 0,05$: ** p — 0,01.

Table 2 Molybdenum content in tissues of the internal organs of white rats after four months of the effect of a commercial-frequency electric field (in mkg% of the moist weight of the organ or tissue)

	A Тканини	B Статистичні показники	C Групи тварин, напруженість поля, кВ/м					
			a 1 група	b 2 група	c 3 група	d 4 група	e 5 група	f 6 група
			1 контроль	2 1 кВ/м	3 2 кВ/м	4 4 кВ/м	5 7 кВ/м	6 15 кВ/м
a)	Печінка	$M \pm m$	42,7±2,6	40,8±2,8	40,8±1,6	29,5±1,5**	26,3±1,3**	23,5±1,2**
b)	Нирки	$M \pm m$	30,8±2,1	27,4±0,8	27,4±0,8	26,9±1,6	32,4±1,9	36,3±1,4
c)	Селезінка	$M \pm m$	8,6±0,4	7,7±0,5	5,7±0,3**	5,7±0,4**	5,6±0,3**	4,8±0,2**
d)	Головний мозок	$M \pm m$	14,0±0,8	14,2±0,7	9,7±0,8**	7,9±0,5**	7,9±0,5**	5,9±0,3**
e)	Серцевий м'яз	$M \pm m$	3,6±0,1	3,6±0,2	3,6±0,2	3,6±0,2	2,7±0,1	2,7±0,1
f)	Скелетні м'язи	$M \pm m$	3,3±0,1	3,3±0,3	3,3±0,1	1,6±0,1**	2,5±0,1**	9,6±0,6**
g)	Шкіра	$M \pm m$	2,9±0,2	3,3±0,3	4,4±0,2**	6,6±0,3**	2,1±0,1**	1,1±0,05**
h)	Кістки (стегнові)	$M \pm m$	1110,6±55,5	1180,0±59,0	1398,2±83,9**	804,5±64,3**	804,5±56,3**	519,4±31,1**
i)	Зуби (різці)	$M \pm m$	1086,8±76,1	1038,3±62,3	1038,3±72,7	968,7±77,5	824,4±41,2*	640,1±25,6**

Key (Tables 1, 2 and 3): A - Tissue B - Statistical indicators C - Group of animals and field intensity, kV/m a - group 1 b - group 2 c - group 3 d - group 4 e - group 5 f - group 6 1 - control 2 - 1 kV/m 3 - 2 kV/m 4 - 4 kV/m 5 - 7 kv/m 6 - 15 kV/m a) liver b) kidneys c) spleen d) brain e) myocardium f - skeletal muscles g) skin h) bones (thigh) i) teeth (incisors)

Table 3 Iron content in tissues of the internal organs of white rats after four months of the effect of a commercial-frequency electric field (in mkg% of the moist weight of the organ or tissue)

A Тканини	B Статистичні показники	C Групи тварин, напруженість поля, кВ/м					
		a 1 група	b 2 група	c 3 група	d 4 група	e 5 група	f 6 група
		1 контроль	2 1 кВ/м	3 2 кВ/м	4 4 кВ/м	5 7 кВ/м	6 15 кВ/м
a) Печінка	$M \pm m$	39,8±2,4	29,5±1,8**	12,6±0,6**	11,5±0,4**	11,5±0,6**	10,9±0,6**
b) Нирки	$M \pm m$	9,1±0,4	9,1±0,4	11,2±0,4**	13,5±0,6**	14,5±0,8**	14,7±1,0**
c) Селезінки	$M \pm m$	4,3±0,3	5,6±0,3*	5,6±0,4*	5,6±0,3*	4,8±0,3	3,4±0,2*
d) Головний мозок	$M \pm m$	12,5±0,8	9,7±0,6*	8,4±0,4**	8,4±0,5**	8,5±0,7**	8,2±0,6**
e) Серцевий м'яз	$M \pm m$	2,8±0,2	2,8±0,2	2,8±0,1	2,9±0,1	2,9±0,2	3,2±0,2
f) Скелетні м'язи	$M \pm m$	0,5±0,02	0,5±0,03	0,5±0,01	0,5±0,03	0,5±0,03	0,4±0,01
g) Шкіра	$M \pm m$	2,6±0,1	2,1±0,08*	2,1±0,1*	2,1±0,09*	1,8±0,09**	1,6±0,06**
h) Кістки (стегнові)	$M \pm m$	37,6±1,5	31,3±1,6**	21,2±1,3**	21,2±1,5**	16,8±0,7**	9,4±0,5**
i) Зуби (різці)	$M \pm m$	28,6±2,0	22,7±1,8	22,7±1,3*	22,7±1,1**	22,7±0,9**	12,8±0,5**

If one takes into consideration the role of copper in hemopoiesis and oxidation-reduction reactions, one can assume that increase of its content plays a certain role in adaptational and compensatory reactions of the organism under the effect of a CFEF.

Of interest are the results of investigation of the copper content in the skin, where at small field intensities to which the organism adapts a decrease is observed, and at a greater intensity of the CFEF an increase of the copper content.

As is evident, copper and molybdenum are physiological antagonists, the interrelations between which have a connected character. In connection with that it is of interest to note that with the exception of the liver under the effect of CFEF disorders in copper and molybdenum metabolism have different directivity (Table 2). Thus, with increases of the field intensity in the spleen, brain, myocardium, skin and hard tissues (bones and teeth) the copper level rises and the molybdenum level drops.

Noted in the skeletal muscles are reductions of the molybdenum content in the tissues of animals under the effect of 4 and 7 kV/m, with gradual accumulation of the trace element under the effect of CFEF of high intensity. Observed in the bones and skin is a "phase character" of the increase of molybdenum, that is, at a field intensity of 1-2 kV/m the quantity of the trace element in the tissues increases, and when the field intensity is increased the quantity decreases.

Of no less interest are the results obtained by us in studying the iron metabolism and distribution. As is evident, iron metabolism in animals and plants is in a certain way connected with copper metabolism, which influences both the absorption and assimilation of iron, which takes an active part in many biochemical reactions proceeding in the organism.

Presented in Table 3 are data on the distribution of iron in the organs. It is evident from the table that a very high level of this trace element is registered in the liver (nearly 40 mg%), and following that are bones containing bone marrow (37.5±1.5 mg%) and teeth (28.6±2.9 mg%). A much smaller quantity of iron (from 0.5 to 12.5 mg%) is noted in other organs and tissues.

Under the effect of a commercial-frequency electric field (CFEF) are observed a fairly well-expressed redistribution of iron, reduction of its content in the liver, brain, skin and hard tissues, and increase in the kidneys, with the content unchanged in the myocardium and skeletal muscles. In the spleen, increase of the iron content is observed at lower levels of the CFEF intensity, and decrease with increase of the field intensity.

Generalizing the results of the investigations, one can conclude that the effect of a CFEF on the organism of white rats leads to change of the balance and distribution of the three investigated trace elements in the organs. Study of the balance and distribution of trace elements among the organs and tissues revealed a rather sensitive indicator of the effect of CFEF, which depends on the intensity of the effect. Reliable changes were found in the distribution of some trace elements in the organs even at a field intensity of 1-4 kV/m, which is biologically ineffective according to other indicators.

The reported data contribute to study of distinctive features of the balance of trace elements in people who have experienced the effect of a commercial-frequency electric field under production conditions, and also to an explanation of the influence on the physiological state of people irradiated by a commercial-frequency electric field of factors contributing to normalization of the balance and distribution of trace elements.

Conclusions

1. The influence of a CFEF on the organism of white rats leads to change of the balance and a redistribution of copper, molybdenum and iron among the organs and tissues of experimental animals.

2. The metabolism and distribution of trace elements depends on the field intensity, which increases with increase of the intensity of the factor of effect.

3. Study of the balance and distribution of copper, molybdenum and iron among the organs was revealed as a rather sensitive indicator of the influence of a commercial-frequency electric field even at field levels which are biologically ineffective according to other indicators.

BIBLIOGRAPHY

1. Gabovich, R. D., and Uzhva, N. F. "The Influence of Water With a Different Mineralization Level on the Organisms of Animals." GIGIYENA I SANITARIYA, 1975, No 10, pp 25-29.

2. Gabovich, R. D., Minkh, A. A., and Mikhalyuk, I. A. "The Influence of the Ultra-high Frequency of a Field of Different Intensity on the Balance and Metabolism of Copper, Manganese, Molybdenum and Nickel in the Organisms of Experimental Animals." VESTNIK AMN SSSR, 1975, No 3, pp 16-22.

3. Gabovich, R. D., Mikhalyuk, I. A., and Fesenko, L. D. "The Influence of the Functional State of the Central Nervous System on the Metabolism and Interorganic Distribution of Copper." FIZIOLOGICHESKYY ZHURNAL AN UkrSSR, 1974, Vol 20, No 2, pp 227-231.

4. Zaydel', A. N., et al. "Emissionnyy spektral'nyy analiz atomnykh materialov" [Emission Spectrum Analysis of Atomic Materials]. Moscow-Leningrad, 1960, 160 pages.

5. Kolomiytseva, N. G., and Gabovich, R. D. "Mikroelementy v meditsine" [Trace Elements in Medicine]. Moscow, 1970, 288 pages.

6. Shvayko, I. I. "Investigation of Gas Exchange in Rats at Different Levels of Manganese and Protein in the Food Ration." In: "Mikroelementy v meditsine" [Trace Elements in Medicine]. Ivano-Frankovsk, 1969, pp 264-266.

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EXPERIENCE WITH DECIMETER WAVE THERAPY AS PART OF COMPREHENSIVE TREATMENT FOR PATIENTS WITH PEPTIC ULCER

Moscow VOPROSY KURORTOLOGII, FIZIOTERAPII I LECHEBNOY FIZICHESKOY KUL'TURY in Russian No 3, 1977 pp 38-41

[Article by A. A. Zhgun, A. A. Ushakov, G. A. Aloyants and V. G. Rebrov, Main Clinical Hospital imeni N. N. Burdenko, Moscow, submitted 18 Jun 76]

[Text] Physical factors are an inseparable component of comprehensive therapy for patients with peptic ulcer; they are pathogenetically warranted, supplementing and enhancing the effects of drugs (Ye. B. Vygodner et al., 1967; Ye. B. Vygodner, 1971). In view of the thermal effect of DMW (decimeter waves; 460 MHz electromagnetic field, 65 cm wavelength), we used this method in the treatment of patients with peptic ulcer.

The objective of this study was to evaluate DMW therapy as one of the factors in a set of therapeutic measures, and to investigate its effects on secretory and evacuatory function of the stomach.

DMW therapy was administered to 113 patients with localization of the ulcerative process in the region of the duodenal bulb, 23 patients with gastric ulcer and 3 patients with gastroduodenitis. Bleeding ulcers and suspected malignification thereof were considered contraindications to DMW.

All of the patients (mainly men ranging in age from 23 to 65 years) were hospitalized for treatment of exacerbation of peptic ulcer and gastroduodenitis. The diagnosis had been confirmed roentgenologically and endoscopically. Cicatrization of the ulcerative lesion was checked by fibrogastroduodenoscopy. Semi rest, diet No 1a, 1b and 1, alkalizing and spasmolytic agents, vitamins were ordered for the patients, and DMW therapy was added on the 14th day of hospitalization. The control group consisted of 57 patients with duodenal ulcer, 17 with gastric ulcer and 6 with gastroduodenitis, who received the same therapy, but without DMW.

The domestic Volna-2 unit served as the DMW generator. A cylindrical emitter, 156 mm in diameter, delivered a flux of energy to the abdominal wall in the exact projection of the stomach, with power of 30 and 60 W. Testing of power generated by Volna-2 revealed that the wattmeter readings were about one-third higher than those on the M-4-2 (milliwattmeter) control instrument, i.e., when the wattmeter showed 60 W, the true power was 40 W with a cylindrical emitter. In the case of an oblong emitter, the wattmeter readings are the same as on the control instrument. In subsequent reporting of our data, we shall indicate the true power of the unit with the use of a cylindrical emitter.

The course of therapy consisted of 8-12 treatments each lasting 10-15 min, with 5 cm distance between the emitter and the patient's body. The treatments were given daily, in the morning; the patients tolerated DMW therapy well; they had a mild sensation of heat in the epigastric region during the treatments, and it intensified at 40 W. The minor pain experienced in the epigastric region by three patients served as the cause of discontinuing DMW, but recheck fibrogastroduodenoscopy failed to demonstrate any complications; the ulcers underwent cicatrization at the usual time.

We tested the effects of DMW on motor and acid-forming functions of the stomach. We used the method of electrogastrography to record motor activity, which does not stimulate peristalsis during the examination and permits evaluation thereof. Gastric bioelectric potentials were recorded on an EGS-4m electrogastrograph. The active electrode was placed on the right forearm and the silent one, on the right leg (V. G. Rebrov, 1974). This method of recording the electric field of the stomach yields a continuous tracing before the treatment, during and after it. Irradiation and electrogastrography were performed 10-15 min after the patient had taken the usual breakfast; we examined 48 patients with the use of 20 W power and 43, with 40 W.

The tracing of change in bioelectric potential was recorded 15 min before operating the Volna-2, 10 min after turning it on and 15-20 min after turning it off. A comparative evaluation was made of three segments on the tracing according to parameters of normal distribution, using the Mir-1 computer. Indices of mean amplitude of 20 successive EGG waves (in mV) served as the base data; a difference between two segments of the tracing was considered reliable only with $P<0.05$.

The results of the electrogastrographic study indicate that bioelectric activity of the stomach diminished at the moment of irradiation and remained lower than initially thereafter in 16 patients exposed to 20 W and 15, to 40 W. The electrogastrographic indices did not change appreciably during the DMW treatment, but then diminished reliably in 23 cases: with 20 W in 11 and 40 W in 12. A distinct depression of bioelectric activity during exposure to DMW followed by return to its initial level was observed in 6 patients (4 exposed to 20 W and 2, 40 W). The electrogastrographic indices rose in 5 cases with use of 20 W and in 5 others, with 40 W. In 19 cases there were no dynamics to bioelectrical activity of the stomach (see Table).

Results of electrogastrophy with administration of DMW therapy to patients with peptic ulcer

Nature of motor activity of the stomach	Number of patients: total	Number of patients given DMW therapy at: 20 W	40 W	P	Mean amplitude before DMW, mV	P_1
Bioelectric activity of the stomach decreased and remained lower than initially	31	16	15	>0,05	0,21±0,02	<0,05
No change in bioelectric activity during treatment, then a decrease	25	11	14	>0,05	0,19±0,01	<0,05
Decreased bioelectric activity during DMW, then increased	6	4	2	>0,05	0,20±0,008	>0,05
Increased bioelectr.activity	10	5	5	>0,05	0,22±0,02	>0,05
Unchanged bioelectr.activity	19	12	7	>0,05	0,15±0,01	
totals	91	48	43			

Note: P is reliability of difference between effects of exposure at 20 and 40 W; P_1 is reliability of difference from group of patients in whom bioelectric activity of the stomach did not change during treatment.

Thus, the results of continuous electrogastrography during DMW therapy revealed that there was reliable depression of motor activity of the stomach in 62 patients tested right at the moment of exposure or immediately after it; however, the EGG indices reverted to the initial level immediately after discontinuing DMW therapy in 6 of these cases. It should be noted that the most marked effect of DMW was observed in patients with hypermotor dyskinesia of the stomach (mean amplitude, 0.19-0.21 mV); there was no gastric motor reaction with biowaves of up to 0.15 mV. Such amplitudes are usually observed in healthy individuals when gastric action currents are derived from the extremities.

We examined the direct effect of DMW therapy on acid-forming function of the stomach by means of intragastric measurement of pH with double-electrode probes. This technique requires preliminary 30-min recording of base acidity during mechanical irritation of the stomach with a probe; the medium pH was determined simultaneously in the body of the stomach and its antral region. "Alkaline time" was determined before turning on the Volna-2 unit by injecting 0.5 g sodium bicarbonate in 30 ml water at 37°C temperature through the probe. After the treatment (at 40 W in most cases), these tests were repeated. This method was used on 37 patients.

The results confirmed the distinct dynamics of acid secretion under the influence of DMW therapy. In both the body of the stomach and the antrum, initial pH ranged from 1.0 to 8.4. After DMW therapy, a decrease in acidity of gastric contents was observed in the region of the body of the stomach in 28 cases and in the pyloric antrum in 25; increases acidity was demonstrated in 5 and 7 cases, respectively, and there was no change in intragastric pH in 9 patients. "Alkaline time" was also tested over a wide range: from 0 to 40 min. In 26 cases, "alkaline time" increased under the influence of DMW therapy; however, this index declined in 6 cases and did not change in 5.

Depression of acid-secreting function under the influence of DMW therapy is somewhat in contradiction to the well-known facts that secretion and acidity of gastric contents increase under the influence of heat. It should be borne in mind that in our study we used a rather mild stimulator of secretion, i.e., the probe introduced into the stomach. Maximum depression of acid-secreting function was observed in patients with hyperacidity prior to the study. The longer "alkaline time" after the treatment was due to depression of expressly acid production by the stomach; however, we cannot rule out a decrease in its evacuatory capacity as well, due to the hypomotor effect of DMW. A mild effect of DMW therapy on acid production was noted primarily in patients with high initial pH indices.

In evaluating the overall efficacy of therapy, we took into consideration the patients' subjective condition, presence or absence of complications of therapy, hospitalization time and cicatrization of the ulcer. Comprehensive therapy aided in rapid disappearance of the pain syndrome and dyspeptic disorders as early as the 7th-10th day of treatment; the patients gained weight and no complications were observed in the course of therapy.

In the case of peptic ulcer with predominant localization of the process in the duodenal bulb, hospital treatment time and, consequently, time of cicatrization constituted less than 35 days in 26 patients of the control group and 56 of those who received DMW therapy. Twenty control patients and 38 of those in the group studied were hospitalized for 36 to 45 days, 13 and 19 patients, respectively, spent over 45 days in the hospital.

Ulcers of the lesser curvature of the stomach were demonstrated in the minority of cases; this group spent more time in the hospital than patients with duodenal ulcer. Treatment lasted up to 35 days in only 8 of the control patients and 12 in the group studied; it lasted 36 to 45 days in 4 and 8 cases, respectively, and over 45 days in 4 and 3 patients. Hospital care of patients with gastroduodenitis did not exceed 3 weeks. Statistical processing of the results of treatment failed to demonstrate reliable differences in time of cicatrization of ulcers with and without DMW therapy.

Thus, the results of this investig tion indicate that there is depression of motor activity of the stomach and acid secretion under the influence of DMW therapy in the case of initial hypermotor dyskinesia and hyperacidity; the effect is not the same if these gastric functions are diminished. Administration of DMW therapy in conjunction with other ulcer-control measures is desirable, particularly in the presence of marked functional (motor or secretory) disorders of the stomach and duodenum.

BIBLIOGRAPHY

1. Vygodner, Ye. V. in "Fizicheskiye faktory v kompleksnom lechenii i profilaktike vnutrennikh i nervnykh bolezney" [Physical Factors in Comprehensive Therapy and Prevention of Internal and Mental Disease], Moscow, 1971, pp 257-273.

2. Vygodner, Ye. B., et al. in: "Primeneniye fizicheskikh i kurortnykh faktorov v kompleksnom lechenii i profilaktike nekotorykh zabolevaniy" [Use of Physical and Balneological Factors in Comprehensive Treatment and Prevention of Some Diseases], Moscow, 1967, pp 14-18.

3. Rebrov, V. G. KLIN. MED. [Clinical Medicine], No 8, 1974, pp 115-120.

10,657
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APPLICATIONS OF LOCAL ELECTROMAGNETIC HYPERTHERMIA IN ONCOLOGY

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[Text] At the present stage of development of oncology, combined and complex methods of treating malignant neoplasms have acquired importance [9]. In this regard, it has become more pressing to search for ways and means of enhancing the effectiveness of drugs and radiation used as components of combined and complex treatment of oncological patients [7, 10, 11, 37]. One of the tasks arising in developing such means is to create conditions that would induce irreversible changes in tumor cells, assure viability of normal tissues and increase antiblastoma protection of the organism.

In principle, it can be considered proven that selective damage to tumor cells can be obtained. But there may be various approaches to actual realization of this possibility. In particular, substantial prospects are implied in taking advantage, for therapeutic purposes, of the differences between normal and tumor cells, with regard to energy metabolism, heat sensitivity and oxygen supply. It must be borne in mind that these differences can be increased appreciably by artificially creating specific biochemical and pathophysiological changes in the organism of patients. Thus, on the basis of theoretical and experimental data contained in the works of V. S. Shapot [32, 33, 34], V. Ya. Havorskiy [35, 36], R. Ye. Kavetskiy [12], Crile [47], von Ardenne [38, 39] and others, several authors have demonstrated that it is basically possible to use artificial hyperglycemia, general and local hyperthermia in combined therapy of oncological patients [5, 19, 27, 28, 48, 62, 77].

There is still much work to be done to define the place of these methods in the set of therapeutic measures for various malignant neoplasms, as well as to optimize techniques for artificial hyperthermia, hyperglycemia, hyperthermia--peroxidation and combinations thereof with drugs and radiation methods of therapy. However, even now, there is no question that hyperthermia, in the appropriate modes, has an inhibitory effect on tumors and enhances antineoplastic activity of drugs and radiation [1, 4, 43, 61, 68, 84, 87].

The required, controllable hyperthermic conditions in a tumor can be obtained by different methods. It was learned that local electromagnetic hyperthermia induced by radiowaves, in particular, is quite promising for enhancement of antineoplastic activity of drugs and radiation [3, 45, 50, 51].

The first reports on the use of radiowaves for therapeutic purposes in oncology are referable to the start of the 20th century [74, 75, 90]. Later on, several works were published dealing with attempts at investigation of various aspects of this problem. However, these studies were not systematic, and methodologically they were not sophisticated enough. In the present decade, the question of using electromagnetic waves in medicine began to draw the attention of many researchers. Reports were published that indicated the expediency of broader development of this direction. The works of Guy [59], Guy et al. [60], Johnson and Guy [63] and Shwan [83] are referable to 1972-1974; they offer a survey of current knowledge on the use of electromagnetic energy for therapeutic purposes in medicine.

It must be indicated that successful development of applications of electromagnetic hyperthermia in therapy of malignant tumors is possible only with due consideration of the distinctions of cytobiochemical, cytophysiological and cytokinetic processes in tumors and normal tissues. In-depth investigation of the effects of radiowaves on the course of these processes is a most important task and this, in turn, makes it imperative to work out flawless informative criteria for objective evaluation thereof.

Electromangetic radiations are "alternating electric and magnetic fields propagating in space at a finite speed, which are interrelated and cannot exist without one another" [25]. The distinctions of their biological effect are determined by the rate of propagation of radiations in space, field oscillation frequency and wavelength. The wide electromagnetic spectrum has three main ranges: ionizing, optical and radiowave. Radiowaves correspond to the electromagnetic spectrum with moderate oscillation frequency of $3 \cdot 10^5$ to $3 \cdot 10^{11}$ Hz [16]. A distinction is made between three main ranges of radiowaves: high frequency (HF), which include long (3000 m, 100 kHz), medium (100 m, 3 mHz) and short (100-10 m, 3-30 mHz) waves; ultrahigh frequency (UHF) with wavelengths of 10-1 m and oscillation frequency of 30-300 mHz, and superhigh frequency (SHF), or microwave range. Microwaves are divided into decimeter (1 m - 10 cm, $3 \cdot 10^2$-$3 \cdot 10^3$ mHz), centimeter (10-1 cm, $3 \cdot 10^3$ - $3 \cdot 10^4$ mHz) and millimeter (1 cm-1 mm, $3 \cdot 10^4$-$3 \cdot 10^5$ mHz) bands.

Research on the biological effects of radiowaves, begun soon after the outstanding discovery of A. S. Popov, continued in subsequent years [20-24, 26, 31 and others]. The main effects of radiowaves on biological systems became known: thermal and nonthermal, therapeutic and deleterious. However, a number of questions are still open, pertaining to the effects of radiowaves of different ranges specifically on particular tissues and the human and animal body as a whole.

The monograph published in 1970, edited by I. R. Petrov [16], which deals specially with these issues is of great scientific and practical value. It cites several hypotheses dealing with the mechanism of action of microwaves: specific thermal effect of electromagnetic waves on tissues, nonthermal coagulation of protein (due to resonance oscillations of side chains in protein molecules), theory of "pearl chains," theory of impaired regulation of function, etc. Other researchers have also referred to these hypotheses [17, 26, 29, 63].

It is noteworthy that the damaging effect of radiowaves is more marked in tissues with impaired or inadequate circulation, and edema and inflammation enhance the thermal effect of microwaves. In the opinion of I. R. Petrov and A. G. Subbota, one cannot rule out applicability of the law of Bergonié-Tribondeau to the action of microwaves; according to this law the sensitivity of tissues is directly proportionate to the degree of differentiation. Consequently, there are grounds to believe that a tumor, with its cytokinetic distinctions [8, 30, 40], defective blood supply and poor delivery of oxygen [13, 18], is more susceptible to the damaging effect of radiowaves, at least when delivered in thermogenic levels, than the same normal tissues. Equally important is the fact that exposure to radiowaves intensifies circulation in tissues [66] and increases delivery of oxygen to them [18]. It may be assumed that these conditions are suitable for improved transport to tumor tissues of drugs, for example, chemotherapeutic agents, glucose, as well as for enhancement of the antineoplastic effect of radiation therapy.

The thermal effect on tissues is the most obvious and practically important effect of electromagnetic radiation in the nonionizing range, which has drawn the attention of medical men. Several beneficial reactions occurring in a pathological site are related to the thermal effect of radiowaves: increased blood flow, associated with elevation of capillary pressure, increased permeability of cell membranes and metabolism. Elevation of temperature from 34° to 40° leads to 77% intensification of metabolism [60]. These reactions, in turn, could lead to further elevation of temperature in tissues. There is acceleration of healing processes in damaged tissue as a result of more intensive transfer of metabolites through cell membranes, higher concentration of antibodies, larger number of leukocytes, increased rate of elimination of toxic products, absorbed bacteria, etc., from areas submitted to treatment [82].

According to Guy et al. [60], Nagelschmidt (1907) was the first to introduce the term "diathermy" (from dia--through and therme--heat) to refer to the relatively uniform heating of tissues under the influence of high-frequency electromagnetic oscillations. This term became so well-established that it is used, in some reports of foreign researchers, to refer to radiowaves even with nonthermal action.

The need to devise an appropriate terminology is more than obvious. The lack thereof makes it difficult to analyze and compare data on the efficacy of electromagnetic waves, since it is often unclear what radiowaves and irradiation modes the authors are dealing with. Yet, the frequency of an electromagnetic field, wavelength, intensity and duration of irradiation are of substantial significance, in order to obtain the required, controllable, local hyperthermal conditions in tissues [64]. The form and dielectric properties of irradiated tissues, mainly the skin, subcutaneous tissue, muscles and other structures with high fluid content are equally important factors in determining the magnitude of the thermal effect [59].

The marked differences in dielectric properties of tissues (the subcutaneous fatty layer, for example, serves as a heat barrier), vascularization and form of irradiated structures make it quite difficult to estimate thermal fields. The use of models ("phantoms") of tissular structures [14, 59] for these purposes only approximately reflects reality. For this reason it is important to have data on tissular thermotopography directly in the course of a radiation session.

Unfortunately, such thermal dosimetry, particularly in the case of decimeter and meter waves, is methodologically a difficult task, since the readings of metal sensors in the range of action of electromagnetic fields are characterized by significant flaws. It would be difficult to exaggerate the importance of direct thermal dosimetry, particularly if we consider the appearance of so-called "hot spots" in tissues. "Stationary waves," due to a different coefficient of energy absorption in tissues with high (skin, muscles, brain, internal organs) and low (fat, bones) fluid content, are the basis for formation of these "hot spots." The waves reflected on the interface of these tissues lead to formation of "hot spots," which are then localized, regardless of dielectric properties of irradiated structures. The "hot spots" present a substantial threat to tissues, overheating of which is not intended by the therapy session.

Yet, the optimum method of electromagnetic hyperthermia should provide for very specific temperature levels not exceeding the danger level (45°C) in different tissues (including superficial and deep, normal and pathologically altered). Unfortunately, we do not yet have a special, general-purpose radiowave therapy machine that would produce very specific, prespecified and strictly regulated general and differentiated local hyperthermia in tissues. The solution is to "screen" the appropriate electromagnetic spectrum in each specific instance, with due consideration of its known properties and potential thermogenic effect on the tumor, depending on the location of the latter, its blood supply, etc.

Let us submit some information on the thermogenic effect of electromagnetic fields on various tissues, depending on wavelength and type of emitter.

Capacitive electrode, induction and induction-capacitive emitters are used for short-wave diathermy. Considerable overheating of the subcutaneous fatty layer (17 times more than the muscular layer) is observed with the use of electrode emitters. The advantage of the induction emitter is that it provides for safe heating of deep tissues (muscles), with retention of lower temperatures in superficial tissues. The serious disadvantage of induction emitters is the inherent heterogeneity of torroidal distribution of temperature, which makes it inconvenient to treat small sections of tissue [60].

SHF electromagnetic waves are the most suitable for overheating a limited part of the body. The shorter wavelength makes it possible to focus energy and deliver it very specifically to particular tissues, situated at different depths, by means of small emitters. Of substantial importance is the fact that the irradiated surface does not come in contact with the emitter. At the present time, 12.6 cm and 65.0-69.0 cm microwaves, with field frequency of the order of 2375-2450 mHz (for example, the domestic Luch-2, Luch-58 units) and 433-460 mHz (domestic Volna-2, foreign Sirotherm, Erbotherm and Pyrotherm machines), respectively, are used in physiotherapeutic practice. In the last few years, work has begun on medical and engineering problems of using microwaves of 33 cm length and 915 mHz frequency [59, 60, 63]. Radiowaves in the decimeter range penetrate deeper into tissues of the living organism, as compared to the centimeter range, and they preclude the conditions for occurrence of "stationary waves" in the skin and subcutaneous tissue; consequently, there is no danger of overheating these tissues. Moreover, the accuracy of dosimetry of therapy is increased [21] and it is easier to monitor the magnitude of absorbed energy [63].

Studies dealing with the use of electromagnetic hyperthermia in oncology are referable primary to the HF and UHF ranges. Research on SHF radiowaves began relatively recently and only experimentally [46, 55, 94, 95, and others].

Analysis of the literature shows that HF and UHF electromagnetic waves enhance the antineoplastic activity of ionizing radiation and chemotherapeutic agents. The results of experimental and a few clinical studies pertaining to the combined use of such hyperthermia and ionizing radiation are submitted in the relatively complete survey of Selawry et al. [84]. Stressing the great potential capabilities of the method as being "very promising in the treatment of neoplasms," the authors correctly indicate that many methodological, pathophysiological, pathobiochemical and other questions pertaining to the problem under discussion remain open.

In spite of the lack of sufficient experimental grounds, some researchers have made a clinical trial of short-wave hyperthermia and ionizing radiation for the treatment of malignant neoplasms. Thus, Muller [74, 75], who used a combination of x-rays and diathermy in the treatment of 100 patients with diverse forms of malignant tumors (breast cancer, carcinoma of the esophagus, lungs, etc.), observed complete regression of neoplasms in 32 cases, a reduction in 36 and further extension of the tumor process was recorded in 32 cases. Analogous results were obtained by other authors in the treatment of patients with sarcoma and cancer using radiation and hyperthermia [42, 56, 57, 85, 92]. Crile [47, 48] became convinced that hyperthermia, particularly short-wave, is capable of "doubling" the antineoplastic effect of ionizing radiation. These data are quite consistent with the results of experimental research, according to which, there is 4- and even 10-fold intensification of the antineoplastic effect of ionizing radiation against the background of hyperthermia [39, 78].

We could continue listing such research [41, 58, 64]. However, we cannot find reliable enough information in these reports concerning the temperature and exposure parameters in tumors with short-wave irradiation, optimum and most desirable variants of combinations of hyperthermia, radiation, courses of chemotherapy and surgical intervention.

Data on histology of changes developing in tumors and normal tissues under the influence of hyperthermia combined with chemotherapy and radiation are of substantial importance. Unfortunately, there are few such studies [38, 39, 73, 79, and others], and there are only isolated ones on the use of electromagnetic hyperthermia, containing no systematized data [52, 53, 67, 79, 80, 81]. The work of Overgaard and Overgaard [76] merits attention; it is based on the results of experimental use of short-wave hyperthermia on 1200 mice with HB anaplastic carcinoma of the mammary gland. Complete disappearance of tumors was observed in 20 and 25% of the cases with exposure for 45 min at 43° and 60 min at 43.5°, respectively. Histological examination made directly after hyperthermia revealed moderate hyperemia of the tumors. In the next 2-5 h, the cytoplasm became shriveled, the cell nuclei became angular; no mitoses were demonstrable after another few hours. The tumor disappeared in 8-14 days, with connective tissue replacing it. The authors evaluate the "selective localization" of necrosis in tumor cells, as well as the rapid growth of connective tissue with concurrent resorption of the tumor, as the result of the specific action of hyperthermia.

As for treatment of oncological patients with local SHF hyperthermia and combination thereof with chemotherapy or ionizing radiation, the Scientific Research Institute of Oncology and Medical Radiology, Belorussian Ministry of Health, has extensive experience in research on this score [3, 4, 6, 15, 27]. Along with a team headed by Academician N. D. Devyatkov, units were developed on the basis of the Luch-2, Luch-58 and Volna-2 machines, and methods were worked out to obtain strictly controlled SHF hyperthermia in tumors, combinations thereof with intraarterial infusion and perfusion of chemotherapeutic agents, as well as radiation.

Local SHF hyperthermia of tissues in the region of tumors (42.8°±0.1°, 60±8 min) combined with normothermal or moderate hypothermal perfusion was used in the treatment of 17 patients with malignant neoplasms of the limbs. The perfusate contained, in addition to chemotherapeutic agents, thermosensitizing and overoxidizng agents. The tumor was completely destroyed in 6 out of 13 patients who underwent surgery after this treatment, and in the 7 others, although marked destruction of tumor elements was observed, viable tumor cells were still demonstrable. The dosage of chemotherapeutic agents (sarcolysin, thiotepa) was 50% smaller than with normothermic regional perfusions (10 cases) and almost one-third less than with hyperthermic perfusions (15 cases) given by the method described by Cavaliere et al. [44], Stehlin [87], Mondovi et al. [7], but with the use of thermosensitizers and agents that overoxidize tumor tissue.

From the standpoint of effectiveness of conventional methods of treatment, amputation of the limb at a proper (high) level was indicated for all 42 of of our patients. However, such amputation was performed on only one of the 17 patients, in whose treatment SHF hyperthermia combined with regional perfusion was used, and the other 16 categorically refused this surgery (extensive resection of the tumor or sparing amputation involving resection of toes and part of the foot was performed in 12 cases; no surgery was performed on 4 patients after perfusion). Nevertheless, all 17 survived for 1.5-3.5 years, and only 2 of them had a recurrence of the tumor after 16 and 24 months. As for the patients who received normothermal or hyperthermal regional perfusions (15 out 25 cases combined with amputation of the limb), there were 6 deaths out of 10 cases and 9 deaths out of 15 at the same follow-up times.

Profound and extensive destructive changes were also demonstrated following SHF hyperthermia of the region of malignant tumors of the limbs (41-42° for 60-120 min) combined with intraarterial administration of chemotherapeutic alkylating agents, 2-8 days after the treatment.

Local SHF hyperthermia of tumors (41-43° for 60-120 min) combined with radiation using short-focus machines, deep roentgenotherapy, telegammatherapy was performed on 70 patients with malignant neoplasms of the skin, soft tissues, breast and other organs (over 500 sessions in all). The experience gained revealed that, in the vast majority of cases, particularly when treatments were repeated, a sharp reduction in neoplasm size is obtained, with development of profound alterative changes in it, to the extent of total destruction of tumor elements. The data on multiple tumors, one of which was exposed only to radiation and the other, to the same dose of radiation but against the background of SHF hyperthermia, are of particular theoretical and practical significance.

The results of microscopic examination of resected tumors revealed that the alterative changes were considerably more marked, even in so-called radioresistant tumors, after SHF hyperthermia combined with radiation.

It is unquestionable that local electromagnetic hyperthermia, using radiowaves in the SHF range, is safe, from the standpoint of controllable temperature, convenient and superior to other methods of local heating. Of course, more knowhow and comprehensive development of the problem are required before the most rational methods, conditions and combinations are defined, as related to localization, form, histological structure of the tumor, etc.

Within the framework of this research, the question of mechanism of damaging effect of hyperthermia on the tumor and its enhancement of antineoplastic activity of chemotherapy and radiation is far from irrelevant. There are already a number of reports on this subject. Most of them stress the selective sensitivity of tumor cell metabolism to temperature. Dickson [49] believes that this sensitivity "could be the Achilles' heel that therapeutists have been searching for for many years." However, the potential of controlled hyperthermia in the treatment of tumors, and particularly metastatic ones, is still unknown.

Research, in which the effect of hyperthermia is considered in relation to the cell cycle of tumor cells, merits a close scrutiny [40, 43, 69, 86, 88, 91, 93]. These investigations permit demonstration of the phases of the cell cycle that are the most sensitive to hyperthermia (M and S), and they are indicative of the possibility of synchronization thereof by means of heat.

Dickson [49] believes that divided doses of heat to tumors have advantages over single heating, at least in cases where tumor cell generation time can be determined. At the same time, the author indicates that it is difficult to obtain information about cell kinetics, and for this reason one should use prolonged (10-12 h) hyperthermia at 42°, when tumor cells would perish, regardless of their position in the cell cycle. We consider this approach to be wrong. It detracts researchers from investigation of the mechanisms of action on tumors of hyperthermia in general and various forms thereof in particular, as well as from searching for optimum combinations of hyperthermia and other forms of therapy, causing investigators to regress toward consideration of hyperthermia as a panacea in the treatment of tumors.

Investigation of the mechanism of the damaging effect of hyperthermia on tumors, as well as the mutually potentiating effects of high temperature, chemotherapy and radiation, is the most pressing task referable to our problem as a whole. There are already grounds to believe that overheating damages the structure of the tumor cell protoplast [11], elicits "labilization" of lysosome membranes [67, 89], irreversible respiratory arrest [39, 70], a marked inflammatory reaction [48], depressed synthesis of DNA, RNA and proteins [71], and increases the immunobiological forces of the organism [39, 54, 65, 93]. Dickson [49] even believes that the specifics of action of local hyperthermia, unlike the antineoplastic effects of chemotherapy and ionizing radiation, consist of intensification of immune reactions due to slow absorption of destroyed tumor cells. It is known that the immunobiological defense capabilities of the organism of oncological patients are depressed, and these changes are aggravated under the influence of radiation and chemotherapy [12]. Studies pursued in the clinic of the Scientific Research Institute of Oncology and Medical Radiology, Belorussian Ministry of Health [2], have shown that the use of general and local hyperthermia and overoxidation in the combined therapy of oncological patients, including chemotherapy and radiation, was not associated with depression of immunological reactivity, and in some cases, impaired indices of immunobiological reactivity, present before treatment, underwent recovery.

To sum up the foregoing, it should be stressed that electromagnetic hyperthermia, particularly local overheating of tumors using an SHF field, is a promising method for enhancing the antineoplastic activity of chemotherapeutic agents and radiation. This question requires special, in-depth and systematic investigation. Successful development thereof is possible, on the basis of joint research involving oncologists (experimenters and clinicians), biologists, biophysicists and specialists dealing with the study of electromagnetic radiations.

BIBLIOGRAPHY

1. Aleksandrov, N. N.; Muravskaya, G. V.; and Fradkin, C. Z. "New Biological Approaches to Radiation Therapy of Malignant Neoplasms," in "IV Vsesoyuznaya konferentsiya onkologov. Osnovnyye materialy" [4th All-Union Conference of Oncologists. Principal Proceedings], Vil'nyus, 1975, pp 87-94.

2. Aleksandrov, N. N.; Risina, D. Ya.; Fradkin, C. Z.; et al. "Immunobiological Reactivity of Patients With Malignant Neoplasms Following Artifical Overoxidation and Overheating of the Tumor," in "Immunologiya opukholey" [Immunology of Tumors], Kiev, 1975, pp 14-16.

3. Aleksandrov, N. N.; Savchenko, N. Ye.; Fradkin, S. Z.; et al. "Possible Use of Local Electromagnetic Hyperthermia Combined with Chemotherapy and Radiation in Complex Therapy of Extensive Forms of Malignant Tumors," in "Aktual'nyye problemy onkologii i meditsinskoy radiologii" [Pressing Problems of Oncology and Medical Radiology], Minsk, Vyp 5, 1975, pp 267-276.

4. Aleksandrov, N. N.; Fradkin, S. Z.; and Malinovskiy, I. I. "Use of Heat in Combined Therapy of Malignant Tumors," VOPR. ONKOL. [Problems of Oncology], Vol 19, No 4, 1973, pp 78-88.

5. Aleksandrov, N. N.; Fradkin, S. Z.; Zhavrid, E. A.; and Toropova, T. V. "Possible Use of Hyperthermia in Combined Treatment of Malignant Tumors," in "II Natsional'nyy kongress onkologov Narodnoy respubliki Bolgarii. Tezisy dokladov" [Second National Congress of Oncologists of the People's Republic of Bulgaria. Summaries of Papers], Varna, 1974, p 80.

6. Aleksandrov, N. N.; Fradkin, S. Z.; Malinovskiy, I. I.; et al. "Method of Using Superhigh Frequency Electromagnetic Fields for Generation of Local Hyperthermia in Combined Therapy of Malignant Tumors," in "Aktual'nyye problemy onkologii i meditsinskoy radiologii," Minsk, Vol 3, 1973, pp 249-254.

7. Aleksandrov, S. N. "Pressing Problems of Experimental Therapy of Malignant Neoplasms," VOPR. ONKOL., Vol 20, No 5, 1974, pp 5-10.

8. Belousova, A. K. "Molecular Bases of Dependence of Cytotoxic Effect of Antineoplastic Compounds on Cell Cycle Phase," Ibid, Vol 18, No 8, 1972, pp 88-96.

9. Blokhin, N. N. "Combined and Complex Therapy of Malignant Tumors," Ibid, Vol 19, No 1, 1973, pp 3-10.

10. Vermel', Ye. M. "Status and Prospects of Drug Therapy of Cancer," Ibid, Vol 15, No 1, 1969, pp 92-104.

11. Vermel', Ye. M., and Kuznetsova, L. B. "Hyperthermia in the Treatment of Malignant Neoplasms," Ibid, Vol 16, No 2, 1970, pp 96-102.

12. Kavetskiy, R. Ye. "Theoretical and Experimental Prerequisites for Combined Therapy of Tumors," in "II Vsesoyuzn. s"yezd onkologov" [Second All-Union Congress of Oncologists], Moscow, 1972, pp 7-10.

13. Knysh, I. T.; Berezovskiy, V. A.; Mosiyenko, V. S.; and Bulakh, A. D. "Effect of Vasodilating Agents and Hyperthermia on Oxygen Tension in Normal and Tumor Tissues," VOPR. ONKOL., Vol 17, No 11, 1971, pp 80-84.

14. Kovach, R. I. "Estimation of Temperature Fields in Biological Objects Heated With Microwaves," MEDITSINSKAYA TEKHNIKA [Medical Engineering], No 6, 1971, pp 12-16.

15. Malinovskiy, I. I.; Zhavrid, E. A.; Neborak, Yu. T.; and Protosenya, M. M. "Biological Effect of Local Superhigh Frequency Hyperthermia Combined With Regional Chemotherapy (Experimental Study)," in "IV Belorusskaya nauchnaya konferentsiya onkologov" [Fourth Belorussian Scientific Conference of Oncologists], Minsk, 1973, pp 377-382.

16. Petrov, I. R. (editor) "Vliyaniye SVCh-izlucheniy na organizm cheloveka i zhivotnykh" [Effect of Ultrahigh Frequency Radiation on the Human and Animal Organism], Leningrad, Meditsina, 1970.

17. Presman, A. S. "Electromagnetic Fields and Living Nature," Moscow, 1968.

18. Rampan, Yu. I. "Oxygen Metabolism and Blood Supply to Tumors and Normal Tissues," VESTN. AMN SSSR [Vestnik of the USSR Academy of Medical Sciences], No 5, 1967, pp 81-87.

19. Savchenko, N. Ye.; Aleksandrov, N. N.; Fradkin, S. Z.; et al. "Use of Hyperthermia in Combined Therapy of Malignant Tumors," ZDRAVOOKHRANENIYE BELORUSSII [Belorussian Public Health], No 2, 1972, pp 3-9.

20. Skurikhina, L. A. "Reaction of the Organism of Syphilitic Patients to Electropyrrhexia Combined With Penicillin," VESTN. VENEROLOGII I DERMATOLOGII [Vestnik of Venereology and Dermatology], No 5, 1954, pp 36-40.

21. Idem, "Use of Decimeter Waves in Physiotherapy," MEDITSINSKAYA TEKHNIKA, No 4, 1969, pp 8-13.

22. Idem, "Present Status of High-, Ultrahigh- and Superhigh-Frequency Electrotherapy," "Trudy Tsentral'nogo NII kurortologii i radioterapii" [Works of the Central Scientific Research Institute of Balneology and Radiotherapy], Moscow, 1971, pp 5-20.

23. Subbota, A. G. "Effect of Pulsed Superhigh-Frequency Electromagnetic Fields on Higher Nervous Activity of Dogs," BYULL. EKSPER. BIOL. I MED. [Bulletin of Experimental Biology and Medicine], No 10, 1958, pp 55-61.

24. Subbota, A. G. "General Characteristics of Thermal Effects of Superhigh-Frequency Electromagnetic Waves," in "Mediko-biologicheskiye problemy SVCh-izlucheniy" [Biomedical Problems of Superhigh-Frequency Radiation], Leningrad, 1966, pp 38-44.

25. Subbota, A. G., and Kovach, R. I. "Vliyaniye SVCh-izlucheniy na organizm cheloveka i zhivotnykh" (edited by I. R. Petrov), Leningrad, Meditsina, 1970, pp 5-16.

26. Tyagin, N. V. "Clinical Aspects of Superhigh-Frequency Radiation," Leningrad, Meditsina, 1971.

27. Fradkin, S. Z. "Basic Possibility of Applications and Methods of Inducing Hyperglycemic, Hyperthermic and Hyperoxic Conditions in the Combined Treatment of Some Forms of Malignant Tumors," in "Aktual'nyye problemy onkologii i meditsinskoy radiologii," Minsk, Vyp 4, 1974, pp 297-309.

28. Fradkin, S. Z.; Savchenko, N. Ye.; Chekhova, Ye. I.; et al. "Chemotherapy in Conjunction With General Controlled Hyperthermia in the Treatment of Generalized Forms of Malignant Tumors," in "II Vsesoyuznyy s"yezd onkologov, Materialy," Moscow, 1972, pp 57-58.

29. Frank-Kamenetskiy, D. A. "Plasma Phenomena in Semiconductors and Biological Effects of Radiowaves," DOKL. AN SSSR [Reports of the USSR Academy of Sciences], Vyp 136, No 2, 1961, pp 476-478.

30. Frankfurt, O. S. "The Cell Cycle in Tumors," Moscow, Meditsina, 1975.

31. Frenkel', G. A. "Electric Fever," Leningrad, 1945.

32. Shapot, V. S. "Biochemical Distinctions of the Cancer Cell and Approaches to Chemotherapy of Malignant Tumors. Present Status of Chemotherapy of Malignant Tumors," in "I Vsesoyuznaya konferentsiya po khimioterapii zlokachestvennykh opukholey" [First All-Union Conference on Chemotherapy of Malignant Tumors], Riga, 1968, pp 6-7.

33. Idem, "Some Biochemical Distinctions of Cancer Cells and Possible Approaches to Chemotherapy of Malignant Tumors," in "Aktual'nyye voprosy sovremennoy onkologii (Tr. seminara po onkologii)" Pressing Problems of Modern Oncology (Proceedings of Seminar on Oncology)], Moscow, Vyp 2, 1970, pp 111-125.

34. Idem, "Correlation Between Tumor and Organism Metabolism," in "Voprosy eksperimental'noy i klinicheskoy onkologii (Tr. VIII itogovoy nauchn. konf. In-ta eksperim. i klinich. onkol. AMN SSSR)" [Problems of Experimental and Clinical Oncology (Proceedings of 8th Scientific Conference of the Institute of Experimental and Clinical Oncology, USSR Academy of Medical Sciences)], Moscow, 1972, pp 48-56.

35. Yavorskiy, V. V. "Pathophysiological Aspects of Isolated Perfusion and Potential Use Thereof to Enhance Efficacy of Antineoplastic Agents," in "Regionarnaya khimioterapiya zlokachestvennykh opukholey" [Regional Chemotherapy of Malignant Tumors], edited by G. Ye. Ostroverkhov and N. N. Trapeznikov, Moscow, Meditsina, 1967, pp 45-60.

36. Idem, "Effect of the Temperature Factor on Antineoplastic Activity and Toxicity of Embichin and Sarcolysin," in "Protivoopukholevyye preparaty v klinike i eksperimente (tezisy dokladov konferentsii)" [Clinical and Experimental Use of Antineoplastic Agents (Summaries of Papers Delivered at a Conference)], Moscow, 1964, pp 81-82.

37. Yarmonenko, S. P. "Universal Approaches to the Control of Tissular Radiosensitivity in Radiation Therapy of Malignant Tumors," VOPR. ONKOL., Vol 21, No 5, 1975, pp 63-73.

38. Von Ardenne, M. "Theoretische und experimentelle Grundlagen der Krebs-Mehrschritt-Therapie. In Vivo Theorie des Garungsstoffwechsels der Krebsgeschwulste. Selective chemische Sensibilisierung der Krebszellen gegen Warme," "Arbeiten aus den Jahren 1963-1966," Berlin, 1967.

39. Idem, "Krebs-Mehrschritt Therapie. In vivo Theorie des Garungsstoffwechsels der Krebsgeschwulste," Berlin, Auflage, Part 2, 2, 1971.

40. Idem, "Krebszellkinetik und Krebs-Mehrschritt Therapie," ZTSCHR. NATURFORSCH., 27, 2, 1972, pp 1547-1566.

41. Arons, J., and Sokoloff, B. "Combined Roentgenotherapy and Ultrashort Wave," AM. J. SURG., May 1937, pp 533-543.

42. Birkner, S., and Wachsmann, F. "The Combination of X-Rays and Short Waves," STRAHLENTHERAPIE, 79, 1949, pp 93-102.

43. Block, J. B., and Zubrod, C. G. "Adjuvant Temperature Effects in Cancer Therapy, CANCER CHEMOTHER. REP., 57, 4, 1973, pp 373-382.

44. Cavaliere, R.; Ciocatto, E. C.; Giovanella, B. C.; Heidelberger, C.; Norecca, G.; and Rossi-Fanelli, A. "Selective Heat Sensitivity of Cancer Cells. Biochemical and Clinical Studies," CANCER, 20, 9, 1967, pp 1351-1381.

45. Chranowa, A. "Irreversible Impairment of Carcinoma Cells by Ultrashort Waves (Experiment on Mice With Transplanted Carcinoma)," Z. KREBSFORSCH., 56, 1, 1948, pp 80-90.

46. Copeland, E. S., and Michaelson, S. M. "Effect of Selective Tumor Heating on the Localization of ^{131}I Fibrinogen in the Walker Carcinoma 256. II. Heating With Microwaves," ACTA RADIOL. THER. PHYS. BIOL. (Stockholm), 9, 4, 1970, pp 323-336.

47. Crile, G. Jr. "Heat as an Adjunct to the Treatment of Cancer. Experimental Studies," CLEVELAND CLIN. QUART., 28, 1961, pp 75-89.

48. Idem, "Selective Destruction of Cancer After Exposure to Heat," ANN. SURG., 156, 3, 1962, pp 404-407.

49. Dickson, G. A. "Hyperthermia in the Treatment of Cancer," CANCER CHEMOTHER. REP., 58, 3, 1974, pp 294-296.

50. Dietzel, F.; Kern, W.; Barth, G.; and Sieg, T. "Tumor Therapy With High-Frequency Hyperthermia Alone (Decimeter Waves)--Experimental Study on Animals," BIOMED. TECHN., 16, 6, 1971, pp 213-220.

51. Dietzel, F.; Kern, W.; and Klobe, G. "Hyperthermia Therapy of Malignant Tumors," MED. KLIN., 68, 6, 1973, pp 182-186.

52. Dittmar, C. "Effect of Ultrasonic Waves on Animal Tumors," STRAHLENTHERAPIE, 78, 2, 1948, pp 217-231.

53. Dyroff, R., and Horvath, J. "Ultrasonic Effect on Human Sarcoma," Ibid, 75, 1, 1944, pp 126-130.

54. Ernst, J. "Erfahrungen und Moglichkeiten der Uberwarmung mittels Uberwarmungslader seit 1948," dissertation, Hambrug, 1967.

55. van Everdingen, W. "Bestrahlungen mit golden von Herz," NEDERLAND. TJUDSCHR. VOOR GENESKUNDE, 82, 1, 3, 1938, pp 284-288.

56. Fuchs, G. "Combined Therapy of Bronchial Carcinoma With Short Waves and X-Rays," RAD. BIOL. TER. [Radiobiological Therapy], 6, 5, 1965, pp 508-511.

57. Guchs, G., and Hofbauer, J. "Experience With Combined Short-Wave and X-Ray Therapy of Bronchial Carcinoma," KREBSARZT, 6, 1956, pp 338-342.

58. Gilchrist, R. K.; Shorey, W. D.; Hanselman, R. C.; de Peyster, F. A.; Yang, J.; and Medals, R. "Effects of Electromagnetic Heating on Internal Viscera: Preliminary to the Treatment of Human Tumors," ANN. SURG., 161, 6, 1963, pp 890-896.

59. Guy, A. "Research on Models, Using Thermographic Methods of Electromagnetic Fields Induced in Biological Tissues," translation from IEEE TRANS. MICROWAVE THEORY TECH., 19, 1971, pp 205-214. "Biological Effects of Superhigh-Frequency Radiation," 1973. Translations of foreign literature, Translation No 3-122, pp 244-255.

60. Guy, A. W.; Lehmann, J. E.; and Stonebridge, J. B. "Applications of Electromagnetic Energy in Therapy," TIIER [expansion unknown], 62, 1, 1974, pp 66-93.

61. Hall, K. K.; Schade, R. D. K.; and Swinney, S. "Effects of Hyperthermia on Bladder Cancer," BRIT. MED., 2, 1974, pp 593-594.

62. Henderson, M. A., and Pettigrew, R. T. "Induction of Controlled Hyperthermia in Treatment of Cancer," LANCET, 1, 7712, 1971, pp 1275-1277.

63. Johnson, C. C., and Guy, A. W. "Effects of Nonionizing Electromagnetic Radiation on Biological Media and Systems," TIIER, 60, 6, 1972, pp 49-82.

64. Korb, H. "A Combination of X-Ray and Short-Wave Therapy," STRAHLENTHERAPIE, 77, 2, 1948, pp 301-303.

65. Lampert, H. "Advantages of Additional General Therapy of Cancer Patients," MED. WELT, 18, 1964, pp 1005-1015.

66. Leden, U. M.; Herrick, J. F.; Wakim, K. G.; and Krusen, F. H. "Preliminary Studies on the Heating and Circulating Effects of Microwaves (Radar)," BRIT. J. PHYS. MED., 10, 1947, pp 177-184.

67. Liebesny, P. "Short and Ultrashort Waves. Biology and Therapy," STRAHLENTHERAPIE, Suppl, 1935, p 19.

68. Lunglmayr, G.; Czech, K.; Zekert, F.; and Kellner, G. "Bladder Hyperthermia in the Treatment of Vesical Papillomatosis," UROL. NEPHROL., 5, 1973, pp 75-84.

69. Makino, S., and Nakahara, H. "Study of Cell Division by Phase Microscopy," J. HERED., 46, 5, 1955, pp 245-251.

70. Mondovi, B.; Ratilio, G.; Strom, R.; Finazzi-Agro, A.; Cavaliere, R.; Moricca, G.; and Rossi-Fanelli, A. "Biochemical Mechanism of Selective Heat Sensitivity of Tumor Cells; Preliminary Results," ITAL. J. BIOCHEM., 17, 2, 1968, pp 101-106.

71. Mondovi, B.; Finazzi-Agro, A.; Rotilio, G.; Strom, R.; Moricca, G.; and Rossi-Fanelli, A. "The Biochemical Mechanism of Selective Heat Sensitivity of Cancer Cells. II. Studies of Nucleic Acids and Protein Synthesis," EUROP. J. CANCER, 5, 1969, pp 137-146.

72. Mondovi, B.; Cavalliere, R.; Moricca, G.; Strom, R.; Can, M.; Rotilio, G.; Finazzi-Agro, A.; Calaga, P.; Caputo, A.; and Rossi-Fanelli, A. "Further Biochemical Studies and Therapeutic Applications of the Selective Heat Sensitivity of Tumors," in "Tenth International Cancer Congress," Houston, Texas, USA, 1970, pp 354-355.

73. Muckle, D. S., and Dickson, J. A. "The Selective Inhibitory Effect of Hyperthermia on the Metabolism and Growth of Malignant Cells," BRIT. J. CANCER, 25, 4, 1971, pp 771-778.

74. Muller, C. "Therapeutic Experience with 100 Combinations of X-Rays and High Frequency in Diathermy of Malignant Neoplasms," MUNCHEN MED. WSCHR., 59, 1912, pp 1546-1549.

75. Idem, "Carcinoma and Treatment Thereof With X-rays and High-Frequency Electricity as Diathermy," STRAHLENTHERAPIE, 2, 1913, pp 170-191.

76. Overgaard, K., and Overgaard, J. "Investigations on the Possibility of a Thermic Tumor Therapy. I. Short-Wave Treatment of a Transplanted Isologous Mouse Mammary Carcinoma," EURÓP. J. CANCER, 8, 1972, pp 65-78.

77. Pettigrew, R. T.; Lult, S. M.; Lundgate, C. M.; and Smith, A. N. "Clinical Effects of Whole Hyperthermia in Advanced Malignancy," BRIT. MED. J., 4, 1974, pp 679-682.

78. Robinson, J. E.; Wizenberg, M. J.; Edelsack, E. G.; and McCready, W. A. "Thermally Enhanced Radiocurability of Mammary Tumors in C-3H Mice," "IV Mezhdunarodnyy biofizicheskiy kongress, tezisy sektsionnykh dokladov" [Fourth International Biophysical Congress, Summaries of Section Papers], Moscow, Vol 1, 1972, pp 289-290.

79. Rohdenburg, G. L., and Prime, E. "Effect of Combined Radiation and Heat on Neoplasms," ARCH. SURG., 2, 1921, pp 116-129.

80. Schereschewsky, J. W. "The Action of Currents of Very High Frequency Upon Tissue Cells. A. Upon a Transplantable Mouse Sarcoma," PUBL.HLTH. REP. (Washington), 43, 16, 1928, pp 927-945.

81. Idem, "Biological Effects of Very High Frequency Electromagnetic Radiation," RADIOLOGY, 20, 1933, pp 246-253.

82. Schliphake, E. 1958, quoted by Guy et al., 1974.

83. Schwann, H. P. "Microwave Radiation: Biophysical Considerations and Standards Criteria," IEEE TRANS. BIOMED. ENG., July 1972, pp 304-312.

84. Selawry, O. S.; Carlson, J. C.; and Moore, G. E. "Tumor Response to Ionizing Rays at Elevated Temperatures; a Review and Discussion," AM. J. ROENTGENOL., 80, 1958, pp 833-839.

85. Sholders, H. S.; Turner, E. L.; and Scott, L. D. "Observations on Results of Combined Fever and X-Ray Therapy in Treatment of Malignancy," SOUTHERN M. J., 35, 1942, pp 966-970.

86. Sisken, J. E.; Morasca, L.; and Kibby, S. "Effects of Temperature on the Kinetics of the Mitotic Cycle of Mammalian Cells in Culture," EXP. CELL RES., 39, 1, 1965, pp 103-116.

87. Stehlin, J. S. "Hyperthermic Perfusion With Chemotherapy for Cancers of Extremities," SURG. GYNECOL. AND OBSTET., 129, 2, 1969, pp 305-308.

88. Suit, D. H., and Scwayder, M. "Hyperthermia: Potential as an Antitumor Agent," CANCER, 34, 1, 1974, pp 122-129.

89. Turano, C.; Ferraro, A.; Strom, R.; Cavaliere, R.; and Fanelli, R. "The Biochemical Mechanism of Selective Heat Sensitivity of Cancer Cells. III. Studies of Lysosomes," EUROP. J. CANCER, 6, 1970, pp 67-72.

90. Westermark, N. "The Effect of Heat Upon Rat Tumors," SKAND. ARCH. PHYSIOL., 52, 1927, pp 257-322.

91. Westra, A., and Dewey, W. C. "Variation in Sensitivity to Heat Shock During Cell Cycle of Chinese Hamster Cells in Vitro," INT. J. RAD. BIOL., 19, 5, 1971, pp 467-477.

92. Woeber, K. "Experimental and Clinical Applications of X-Rays Combined With Other Therapeutic Methods in Skin Tumors," in "Korpereigene Abwehr und bosartige Geschwulste," Haug Verlag, Ulm/Donau, 1957, pp 127-129.

93. Wust, G., and Prang, L. "Effect of Hyperthermia on Growth of a Heterotransplanted Human Sigma Carcinoma (GW-39 Tumor," ZTSCHR. KREBSFORSCHUNG UND KLINISHE ONKOLOGIE, 79, 3, 1973, pp 204-213.

94. Zimmer, R. P.; Ecker, H. A.; Popovic, V. P. "Selective Electromagnetic Heating of Tumors in Animals in Deep Hyperthermia," IEEE TRANSACTION, THEORY AND TECHNIQUE, 19, 2, 1971, pp 238-244.

95. Zippel, H. H. "Comparative Macroscopic and Microscopic Study of 3,4-Benzpyrene-Induced Fibrosarcoma in Rats Treated with Hyperthermia, Hyperthermia and X-Radiation, Hyperthermia and a Cytostatic Agent," dissertation, Hamburg University, 1969.

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PHYSICOCHEMICAL MECHANISMS OF THE BIOLOGICAL ACTIVITY OF MICROWAVES

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[Article by E. Sh. Ismailov and S. M. Zubkova]

[Text] The authors survey publications on the mechanisms of the biological effect of microwaves at the molecular, subcellular, and bodily levels. They point out the most promising directions for further studies in this area.

The development of radioelectronics and communications engineering leads to a wider utilization of sources of electromagnetic fields in many spheres of human activities. As a result of this, the artificial electromagnetic background of the environment is increasing. In many instances, the intensity of electromagnetic fields in the vicinity of powerful sources is by several orders higher than the natural background which interacted during the evolution of living nature [16].

The most biologically active and, consequently, more dangerous for man among the entire spectrum of electromagnetic waves are superhigh-frequency (SHF) electromagnetic fields, or microwaves.

The vast literature on this problem treats, chiefly, physicohygienic and clinicophysiological aspects of the problem both in our country [5, 6, 24, 33, 34] and abroad [8, 44-46, 54]. However, without a biophysical approach to this problem it is impossible to establish scientifically substantiated maximum permissible levels (MPL) of irradiation for the population residing in a zone of exposure to electromagnetic fields. Evidently, the absence of such information can be explained by the fact that the MPL values accepted in the USSR and the U.S.A. differ by more than one order [4, 38].

It should be mentioned that radio waves of the SHF range are used more and more widely for treatment of musculoskeletal, nervous, gastrointestinal, and other diseases [3, 26]. Microwaves can also be used in diagnosing diseases. However, it is also impossible to use SHF fields in physiotherapy sufficiently effectively without the knowledge of the initial mechanisms of the action of microwaves on biosystems of various levels of organization, first of all, on biological membranes.

We have attempted to generalize the published data on the primary mechanisms of the biological activity of microwaves.

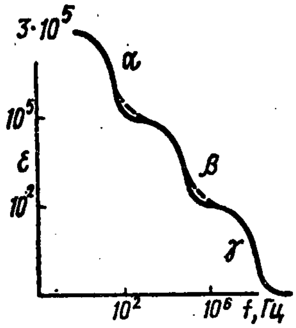
Physical Principles of the Biological Activity of Microwaves

Electromagnetic waves of superhigh frequencies (from 100 MHz to 100 GHz) are a form of electromagnetic radiation, i.e., a wave motion connected with magnetic and electrical forces.

If an electromagnetic field acts upon a medium containing free charges and dipole molecules, then two main processes take place in it: relaxation oscillations of dipole molecules causing dielectric losses and oscillations of free charges causing conductivity losses. The relation between these two types of losses is expressed by the loss tangent $tg\delta$:

$$tg\,\delta = \frac{\sigma}{\omega\varepsilon'\varepsilon_0},$$

where $\mathcal{E}'$ is the relative dielectric permittivity of the medium; σ is the specific conductance; $\mathcal{E}_0$ is the absolute dielectric permittivity for a vacuum.



Dependence of dielectric permittivity (ε) of the muscular tissue on the frequency of the acting field [54]. Designations are given in the text.
Key: 1. Hertz

Since $tg\delta$ depends only on the frequency, the same medium will have different conductivity for different frequencies, i.e., there is a variance in the electric conductivity. Variance of electrical parameters of biological tissues in electromagnetic fields was discussed in works by H. Schwan [38, 52-54]. The figure shows the variance curve of dielectric permittivity ($\mathcal{E}$) of the muscular tissue. Three main relaxation areas are prominent in it: α (Hz-kHz), β (MHz), and γ (GHz) (solid curve) -- and finer structural relaxation: α_1, β_1, and δ (interrupted curve). This curve is typical for all tissues with a high water content.

H. Schwan believes that such intracellular membranes as endoplasmic reticulum connected with the external cell membrane may be responsible for α-dispersion in all tissues having similar structures. It is assumed that the relaxation of anti-ions in charged cell surfaces is the mechanism of α-dispersion. On excited membranes, self-relaxation of charges takes place, which can make an additional contribution to α-dispersion (α_1). Heterogeneity of biological tissues is responsible for β-dispersion. Rotating protein molecules having a dipole moment yield a small addition to the "tail" of β-dispersion which is termed β_1. Subcellular structures, such as mitochondria, the nucleus, and others, also contribute to β-dispersion. Since these structures are small in comparison with the cell itself, their relaxation frequencies are higher, and the overall contribution to the electric losses is smaller than for the cell as a whole. Between the β and γ dispersion regions, there is a region of δ -dispersion (300-2000 MHz) resulting from the rotation of the lateral groups of protein molecules, as well as from the relaxation of protein-bound (or structural) water. Dipole molecules of water are responsible for γ-dispersion.

Gradual complication of biological substances affects their dielectric properties. Solutions of electrolytes show only the γ-dispersion characteristic of water. Biological macromolecules also show δ -dispersion caused by bound water and lateral groups of protein molecules. If the cells have a charge, the α-membrane mechanism resulting from anti-ion relaxation completes the picture of the β and γ dispersion. During self-relaxation of charges, an additional α-mechanism appears on the excited membranes.

Analysis of these general regularities indicates that the dielectric properties of biological media, macromolecules, and cells determine the interaction of these systems with the electromagnetic field.

It has been established that liquid tissues (blood, lymph) and tissues with a high water content (muscles, liver, and others) have higher values of dielectric permittivity and lower values of resistance in comparison with tissues with a low content of water (fat, bones) [38]. Therefore, the methods for measuring conductivity or dielectric permittivity can be used for determining the degree of moisture in fat tissues. When biosystems are irradiated with microwaves of sufficient intensity, the thermal effect is most pronounced. Depending on the depth of the penetration of microwaves into the tissues (or the wavelength), as well as the thickness and electrical properties of the tissues, the ratio of heat released on the surface of the body (skin) and in deeper layers (fat layer and muscles), will differ. The absorption of the microwave energy in tissues depends also on the linear dimensions of the animal or, more correctly, on the ratios of the dimensions of the subject and the irradiation wavelength (λ). If the dimensions of the subject are small in comparison with λ , it can absorb more energy than the energy which falls on its cross section [29]. The degree of heating of the organism or its individual tissues depends on the thermoregulation mechanisms the most important of which is the blood flow.

Some articles discuss the problem of the possibility of "specific" heating of a part of the exposed system in relation to the entire volume of the medium (for example, raising the temperature of the cells in a suspension without any noticeable heating of the entire suspension). However, it has been shown [50, 51] that the selective raising of the temperature ΔT depends on the square diameter of the particle:

$$\Delta T = K \frac{W \cdot d^2}{C},$$

where W is specific absorbed irradiation rate; d is the diameter of the particle; C is the thermal conductivity of the system. For subjects of 0.1 mm and less, such heating does not exceed $1\text{-}5 \cdot 10^{-3}$ degrees C.

Along with the thermal effect of microwaves caused by conductivity losses and dielectric losses, there is a resonance effect of the electromagnetic field on the protein and enzyme-substrate complexes [22, 23, 29]. It is due to the functional dependence among the rates of the biochemical reactions, dielectric properties of the interacting enzymes and substrates, and the frequency characteristics of the acting electromagnetic field. The effect of the electromagnetic field on the interaction among the molecules of the enzyme and the substrate, antigen and antibody, etc., can also be explained by the presence of conformational oscillations in macromolecules (proteins, enzymes, nucleic acid) corresponding to SHF and lower-frequency ranges. Synchronously oscillating macromolecules and cells combined into organelles (nucleus, mitochondria, ribosomes, and others) are responsible for the variations in the dimensions and shapes of these organelles which, in turn, form synchronously oscillating assemblies [39, 56]. Synchronously oscillating assemblies of macromolecules connected with the surfaces of the cells will lead to the oscillations of the latter and synchronization of oscillations at the cellular level [39]. The effect of microwaves on these oscillation processes at various levels of macromolecular organization can amount to synchronization or desynchronization depending on the frequency range and modulation characteristics of the acting electromagnetic field. The synchronization of the oscillations of macromolecules and cells, as well as their mutual orientation by means of electromagnetic interaction in various frequency ranges have been confirmed experimentally [29].

The variance curve of dielectric permittivity shown above (Figure) indicates an important role of biological membranes in the response of cells and tissues to an electromagnetic field up to frequencies of the order of 10 MHz. Beginning with 100 MHz, cell membranes become practically short-circuited, and the main contribution to the absorption of the electromagnetic field by cells and tissues is made by the ions and molecules of the water [38]. These traditional ideas, as well as the small thickness of membranes in comparason with the overall volume of the cell, made it possible for Schwan [52] to make a conclusion about the insignificant role of membrane structures in the interaction with SHF fields. However, in another work [38] Schwan proposes that SHF methods of measuring dielectric permittivity can be used for the analysis of biological membrane systems and to reveal the role played by structural or bound water in their functions. In essence, the author recognizes the possibility of predominant absorption of SHF energy by "structural" water in biomembranes. This is also supported by the fact that the dielectric permittivity of hydrated protein (hemoglobin) decreases by more than three times when the frequency changes from 0.1 to 1 GHz [38]. This decrease is explained by the changes in the dielectric properties of bound water in the above-mentioned frequency range and the possibility of different contributions of polar groups of protein molecules in the process of electric polarization at various frequencies,which, evidently, plays a definite role in the mechanism of the action of microwaves on biological membranes. Finally, the modern concepts of cooperative processes occurring in the cell layer adjacent to the membrane -- glycocalix -- which regulates such important functions of the cell as the absorption and transfer of various substances, electrical charges, immunological reactions, adsorption [27] and increases the effective thickness of the membrane to 2000 Å [41], also indicate the participation of membrane in the responses to the action of microwaves.

In recent years, it has been suggested that the effect of microwaves can be explained on the basis of detecting a certain form of direct current within the body. It has been shown experimentally that it is possible to detect alternating current of a membrane cell in experiments with infusoria [9, 29]. In Schwan's opion [38], rectiffed voltages which are excited by fields weak from the viewpoint of the thermal effect, are by two orders smaller than the rest potential of the membrane (70 mV) and, therefore, there cannot be any substantial effect for the excitable membrane. However, the ability of excitable formations for the summation of subliminal pulses does not exclude the possibility of detection, particularly in synaptic membranes [41].

Effects of Microwaves on the Structure and Function of Biological Membranes

Studies in this area have been started relatively recently. First, indirect data were obtained indicating a substantial role of membranes in the reponses of cells to SHF irradiation. On the basis of the fact that paramecia have an excitable structure corresponding to the electric-shock response (EShR) to direct and alternating current pulses, studies were conducted on the action of an SHF field [9]. In paramecia, the EShR appeared for SHF field pulses of the range of 2.4-3 GHz of various lengths. The threshold value of the intensity of the microwaves at which the response appeared was found to be inversely proportional to the length of the pulses. The subliminal strength of the electromagnetic SHF field caused the sensitization of the paramecia to alternating current pulses.

It has been suggested that this response of paramecia is caused by enzymochemical shifts in their external membrane (pellicle). In order to verify this assumption, threshold voltage of the alternating current causing the EShR was measured under the following conditions: 1) in the presence of neostigmine blocking the effect of cholinesterase and lowering the excitability of the paramecia, or cystein acting upon the sulfhydryl groups of the protein and also reducing their excitability; 2) in the presence of the same substances along with SHF irradiation increasing the excitability; 3) with SHF irradiation in the ordinary medium. It was found that the SHF field compensated the action of neostigmine or cystein. This is explained by the restoration of the disturbed dynamic balance between free acetylcholine and cholinesterase as well as by the inhibition of the oxidation of sulfhydryl groups.

Yu. I. Kamenskiy [19] studied the effects of an SHF field on the functional state of a frog's nerve and the parameters of a nervous impulse during irradiation with continuous (frequency of 2.4 GHz of various intensities) and pulsed (frequency of 3 GHz, average intensity 10 mw/cm^2) microwaves. Under the effect of continuous microwaves which heated the nerve by two degrees C in the course of 20 minutes, the conductance rate increased by 16 $\pm$ 4.5 percent, and the refractory phases shortened slightly. This became more intensive as the intensity of irradiation increased. Pulsed fields, along with increasing the conductance rate by 10 percent, increased the excitability of the frog's nerve. More detailed investigations of the dependence of changes in the parameters of the nervous impulse on the intensity of the SHF field showed that, as the power of the microwaves grew, the amplitude of the biopotentials, the conductance rate of the excitation and the amplitude of hyperpolarization increased, the ascent phase shortened while the descent phase of the nervous impulse remained the same, and the hyperpolarization phase lengthened. After the termination of irradiation, the parameters of the nervous impulse returned to the initial level in the course of 5-15 sec [20].

The above data make it possible to assume that the effects of microwaves on nerve structures are based on the changes in the membrane of nerve fibers which may lead to a decrease in the value of the membrane potential and the appearance of spontaneous impulse activity (for example, in the case of direct reception of microwaves) [12]. Recently, it was revealed that the membrane potential of the nerve cells of isolated ganglia of a mollusk decreases under the effect of an SHF electromagnetic field [25]. Studies were also conducted on the effects of microwaves of the centimeter range (λ=7.65-5.40 cm) on Opalina ranarum [11]. The effect of microwaves was evaluated by the decrease of the capacity component of the cell impedance by the bridge method with the aid of microelectrode techniques. It was shown that the decrease of the capacitive component is expressed by the equation

$$C_t = C_0\left(e^{-\frac{7t+0.8t_e}{t_e}} - \frac{7t}{12t_e} + \frac{7}{12}\right),$$

where C_t is the capacitive component of the cell after the t-th minute of microwave exposure; C_o is its initial value; t_e is the time during which the death of the cell occurred.

Further studies showed that the decrease of the capacitive component is fully reversible if SHF irradiation is stopped. This is followed by the phase of irreversible changes. The decrease of the value of the capacitive component (C_t') due to irreversible changes is described by the equation

$$C_t = \begin{cases} C_0 & \text{at } \frac{7t}{t_e} < 2 \\ \frac{5}{7} C_0 \left[0{,}4 + Y_0\left(\frac{28t - 8t_e}{5t_e}\right)\right] & \text{at } \frac{7t}{t_e} > 2 \end{cases}.$$

Here $Y_0\left(\frac{28t - 8t_e}{5t_e}\right)$ is the Bessel function of the first kind of the zero order. By definition:

$$Y_0(x) = \sum_{s=0}^{\infty} \frac{(-1)^s}{(s!)^2} \cdot \left(\frac{x}{2}\right)^{2s}.$$

In order to determine the causes of the decrease of the capacitive component, the values of active resistance (R_M) and capacitance (C_M) of the cell membrane will be introduced on the basis of the condition of the balance of the bridge circuit:

$$R_M = \frac{(R - R_э)^2 + (\omega C R R_э)^2}{R - R_э - (\omega C R)^2 R_э},$$

$$C_M = \frac{R^2 C}{(R - R_э)^2 + (\omega C R R_э)^2}.$$

Here, R is the ohmic component of the cell impedance; C is its capacitive component $w = 2\pi f$ (f is the frequency of the testing current); $R_э$ is the resistance of the active microelectrode.

It was revealed that there was a sharp decrease in R_M and a slight decrease in C_M under the effect of the SHF field, which indicated a possible change in the structure of the membrane and its permeability. These data made it possible to start direct studies on the physicochemical mechanisms of the membrane activity of microwaves.

E. Sh. Ismailov [13] studied the effects of microwaves of the 1009 MHz range with an intensity of 45 mW/cm^3 on the permeability of human erythrocytes for potassium and sodium ions. Irradiation was conducted in the course of 30 minutes under thermostatic conditions at a temperature of 37 degrees C. It was shown that under the influence of a SHF field the yield of potassium from the cells increased in comparison with the temperature control. At the same time, the penetration of sodium into the cell increased, i.e., the concentration gradient of these ions on the membrane of the erythrocytes decreased. Additional incubation of the erythrocyte suspension at a temperature of 37 degrees C in the course of 30 minutes intensified the effect. Then, a gradual restoration of the initial gradients was observed.

In order to establish the possible route of the action of microwaves on the permeability, the active transport of ions in erythrocytes was inhibited by means of monoiodacetate. SHF irradiation of such erythrocytes caused additional exit of potassium from the cells and intake of sodium in comparison with the control in which erythrocytes were subjected only to the action of the inhibitor. Thus, it was established that microwaves accelerate the diffusion of ions with respect to the concentration gradient through the pores in the membrane and simultaneously inhibit the active transport of ions. The possible molecular mechanisms of such action of microwaves were discussed [14, 15] on the basis of two main processes which lead to the absorption of SHF energy in biological systems: relaxation of oscillations of dipole molecules of water leading to dielectric losses and oscillations of free charges leading to conductivity losses. If the biological medium were homogeneous, then the only effect of the action of SHF irradiation should be thermal [38]. However, biological membranes determining the normal functioning of living systems differ substantially from the environment with respect to their electric properties (including those within the SHF range).

Investigations of recent years have shown that cross-linked water plays an important role in the stabilization of the structure of protein molecules [2] and in the protein-lipid interaction in biomembranes [1, 55]. The characteristic frequency of such water lies in the area of the decimetric radio waves [38]. Therefore, dielectric losses of microwaves of this range in cross-linked water must be higher than in the ordinary water. Most likely, SHF energy losses will cause a phase transition of cross-linked water into a more liquid state, and this, in turn, must lead to conformational changes of protein molecules and changes in the degree of protein-lipid interaction in the cell membrane. Conductivity losses at the membrane surface will also be higher than in the rest of the volume of the cell, since the concentration of ions and ionogenic groups of macromolecules with the corresponding characteristic frequencies is greater here in comparison with the intracellular and intercellular fluid. Thus, more SHF energy is absorbed in biomembranes than in the surrounding solution. Some of the energy is dissipated in the form of heat and raises the overall temperature of the system, and the other part is spent on the destruction of the hydrate covering of the ionized membrane surface and phase transition of water participating in the hydrophobic interactions of the membrane components into a more mobile state. Both of these processes cause disturbances in the molecular organization of membranes leading to changes in their functions.

Changes in the permeability of erythrocyte membranes under the effect of microwaves were confirmed by V. M. Shtemler [40]. Under the same conditions as in our experiments [13], V. M. Shtemler determined unidirectional fluxes of potassium and sodium ions from the external medium into erythrocytes. It was reliably shown that the intake rate of potassium decreased by 15 percent and the intake rate of sodium increased by 10 percent when erythrocytes were irradiated with a SHF field with an intensity of 50 mW/cm^3. No dependence of the effect on the irradiation frequency was revealed in the frequency range of 898-2340 MHz. The dependence of the rate of potassium intake in erythrocytes on the intensity and length of exposure at a frequency of 2340 MHz was also studied. It was established that the threshold intensity of exposure lies in the region of 1-10 mW/cm^3. Changes in the potassium intake rate had phase characteristics. First, this rate decreased (minimum rate 20-30 minutes after the beginning of irradiation), then the rate increased gradually and the sign of the effect changed to positive, and, finally, there was again the phase of negative shifting of the rate of potassium intake in erythrocytes. This time dependence of the changes in the transport rate of potassium ions the author explains [40] by the fact that two different processes take place during SHF irradiation: linear decrease in the transport rate of ions in time and autoregulation of the transport rate in the mode of overregulation with a damped amplitude. The latter process is also responsible for the restoration of the equilibrium rate of potassium intake which is observed 90 minutes after the termination of irradiation. Prolonged exposure (100 min) to an SHF field with an intensity of 50 mW/cm^3 stops autoregulation.

The observed effects are explained by the "destruction" of the erythrocyte membrane which can lead to irreversible changes if the intensity and length of exposure are great. The basis of these effects is the preferential absorption of SHF energy on the membrane surface [40]. At the same time, this absorption is connected, not very aptly, with the possibility of microthermal effects on the membrane. The microthermal effect, if it actually takes place, must be connected with selective heating of the system. Such temperature increase at the membrane surface can hardly be expected without the overall heating of the system because, due to thermal conductivity and the very small thickness of the layer, the excess thermal energy must dissipate immediately into the surrounding space. If we assume that the temperature of the layer increases by 0.1 degree C, then even at a thickness of 100 Å, a gradient of 10^5 degrees C must be maintained on the membrane surface. Therefore, in our opinion, it will be more correct to consider that part of the energy absorbed at the membrane surface dissipates in the form of heat and contributes to the heating of the entire system, and part of it goes for the phase transition of the cross-linked water of the membrane into a more mobile state.

Later, changes in the permeability of cells were also discovered by foreign scientists [42, 48].

S. M. Zubkova [10] studied the effects of microwaves on electron-transferring membranes of mitochondria at frequencies of 500, 1000, 3000 MHz and intensities of 2 to 90 mW/cm^2 under thermostatic conditions at a temperature of 34 degrees C. In the intensity region of 2 to 20 mW/cm^2 at frequencies of 1000 and 3000 MHz and up to 40 mW/cm^2 at 500 MHz, microwaves increased the energizing of mitochondria which had been somewhat decreased as a result of the raising of the temperature to 34 degrees C. As the intensity of the action increased, the "normalizing" effect of microwaves decreased, and at the intensity of 30 mW/cm^2 (for frequencies of 1000 and 3000 MHz) and 50 mW/cm^2 (for 500 MHz) the effects of the action of the thermal factor and microwaves became comparable. Further increase in the intensity of microwaves caused the dissociation of respiration and oxidative phosphorylation. The change of the mitochondria to low-energy state was accompanied by an increase in the level of their superweak luminescence, which indicated the intensification of the processes of peroxidization of unsaturated lipids in mitochondrial membranes [7]. Both of these effects -- the energizing and deenergizing of mitochondria under the effect of microwaves -- are more marked in an alkaline medium (pH 8.5) than in a neutral or particularly an acid medium (pH 6.2). Since it is known that alkalization of the medium contributes to the labilization of the membranes of mitochondria at the expense of the increase in their hydrophilic properties [21], there is reason to assume that the observed effects are connected with the action of microwaves on the water linked with the surface layers of the membranes. It is no coincidence that greater changes in the respiratory and phosphorylating activity of mitochondria were obtained under the effect of decimetric waves; it is in this range that the relaxation frequencies of cross-linked water are present [38]. The energization of mitochondria can be connected with the regulating effect of microwaves on the structure of the hydrate covering disturbed by the action of heat which determines the conformation of the protein part of the membrane and its connection with the lipid component. High intensities of microwaves cause the melting of the ice-like structure which affects the conformation of the membrane and contributes to the dissociation of respiration and phosphorylation (de-energizing effect). The intensification of superweak luminescence of mitochondria also indicates changes in the membrane conformation.

In recent years, an attempt has been made to study the possibility of changing the structure of erythrocyte membranes under the effect of decimetric radio waves of various intensities [17] by the method of infrared spectroscopy and by studying deuterometabolism which makes it possible to evaluate the degree of accessibility of peptide atoms of hydrogen in proteins [36]. It has been revealed that SHF irradiation in the range of 1009 MHz with an intensity of 45 mW/cm^2 results in a slight conformational rearrangement of molecules in the membrane, but does not cause the change of α-spiral or ball into the β-structure. In the course of 36-38 minutes, deuterometabolism shows a more marked change of the band amide II about 1540 cm^{-1} into a band of 1450 cm^{-1} in the irradiated shadows of erythrocytes. The observed effects depend on the intensity of the SHF field -- they disappear at intensities of 5-8 mW/cm^2 and lower.

Thus, microwaves affect the molecular organization of unexcitable biomembranes, as well as the function of unexcitable, excitable, and electron-transferring membranes, but their influence is not connected with temperature changes of the system or its individual parts. This influence is due to the preferential absorption of SHF energy both on the membrane surface (chiefly at the expense of conductivity losses), as well as in the membrane itself (at the expense of dielectric losses).

Action Mechanisms of Microwaves at the Level of the Whole Body

Since absorption of microwaves is connected with the transformation of their energy into thermal energy, one of the marked responses of an animal body to whole-body irradiation with microwaves of medium and high intensities is the rise of the body temperature. It has been shown [49] that in the process of the irradiation of animals, there can be three phases in the changes of rectal temperature depending on the intensity of irradiation: a slight rise in the temperature, a period of equilibrium state, and a rapid rise of temperature leading to irreversible impairment of thermoregulation and death of the animal. The authors treat this dynamics as the manifestation of the thermal stress effect of microwaves. However, a number of experimental data refute this hypothesis. Comparison of the thermal effect of microwaves (24 GHz) and infrared rays of identical intensities showed that microwaves cause four times greater rise of the body temperature and that animals die when the length of exposure to microwaves is eight times shorter than the length of irradiation with infrared rays [47]. These studies show that the effect of microwaves of high and medium intensities cannot be explained just by the thermal effect. A. S. Presman [28, 29] proposed to treat the action of microwavesof thermal intensities as "nonthermal" but progressing against the background of tissue heating. Whole-body irradiation of animals caused a rise in the body temperature only at intensities over 10 mW/cm^2, and this value was found to be approximately the same for pulsed and continuous microwaves of the decimetric and centimetric ranges [29]. When irradiated with millimetric waves with an intensity of 10 mW/cm^2, the temperature increased by 0.4-0.5 degree C [28]. The cause of this "universality" of threshold intensities is in the fact that, at 10 mW/cm^2, the energy which changes into thermal energy (about 5 mW/cm^2) is approximately equal to thermal losses per one cm^2 of the body surface of man and warm-blooded animals at normal conditions of the environment [29].

Soviet researchers [5, 6, 33] were first to show convincingly that microwaves of all ranges at irradiation intensities which do not cause the thermal effect are far from indifferent to the living organism. Chronic exposure to microwaves of low intensities causes considerable functional disorders in the body [33]. Disorders of physiological functions of the body are not caused by direct action of microwaves on physiological processes, but indirectly through the neurohumoral regulation of these processes [28, 33]. When a whole body of an animal is exposed to microwaves, the peripheral nervous system, chiefly, reacts; the response of the central nervous system is a reflex response. A direct response of the structures of the brain to the microwave action is also possible [37].

Reversible effect of microwaves on the function of the nervous system shows itself in two main forms: in the form of responses indicating functional changes in the parasympathetic part of the vegetative nervous system (slowing down of the rhythm of heart contractions, lowering of arterial pressure, lowering of the cholinesterase activity, etc.),and in the form of disorders in the functional state of the brain structures (inhibition of the conditioned-reflex activity, lowering of the sensitivity to sound stimulation, changes in the electroencephalogram, impairment of interneuron connections in the cortex, and others). These manifestations of the nonthermal action of microwaves upon the nervous system were observed in the entire range from very low intensities of irradiation (on the order of tenths of a milliwatt per 1 cm^2). The overall nature of the response does not depend on the wavelength but the degree of manifestation of the observed changes depends on the wavelength: disorders in the function of the brain become more intensive as the wavelength increases, and the vagotonic responses, on the contrary, decrease. This dependence is correlated with the increase in the penetration of microwaves into the tissues as the wavelength increases [28, 33]: when animals were irradiated with millimetric waves, the most marked morphological changes were observed in cutaneous ceptors, and when they were exposed to centimetric waves, disturbances in the interneuronal connections were found in the cerebral cortex. The results of studies on the rhythm of cardiac contractions in animals in the process of irradiation with microwaves (2.4-3 GHz) confirmed the reflex origin of responses due to the action of microwaves on concutaneous receptors [28]. Among nervous tissues, the cerebral cortex and diencephalon structures, especially hypothalamus, are particularly sensitive to the action of microwaves [5, 6, 32, 33]. Changes in the functions of the nervous system occurring under the effect of microwaves are not specific for this type of stimulation. Such changes occur as a result of any method of stimulation or changing the excitability of the central or peripheral nervous system. Therefore, it is natural that the action of microwaves on the nervous system is determined either by the stimulation of nerve cells or by changes in the excitability of nervous tissues. In fact, these changes were detected at the level of the entire body isolated neuromuscular formations (neuromuscular preparation of a frog, isolated ganglion of a mollusk), and in experiments with protozoans [9, 17, 18, 25, 32, 33, 37, 41].

The mechanisms of the appearance of the above effects of the influence of microwaves can be approached on the basis of the examination of three types of interaction of the body with this factor: inadequate energy interaction, energy-information interaction, and information interaction [30, 31].

The inadequate energy interactions should include the results of the influence of microwaves of high intensities leading to lethal termination. In these cases, the energy of the acting factor exceeds the normal energy needs of the body. The response to this inadequate influence passes through several phases. As long as the energy absorbed in the body causes changes which do not disturb homeostasis substantially, the defense systems are not put into action -- this is a tolerant phase; as the action continues, there develops the phase of resistance or adaptation, when systems of the body compensating the effects of the influence react successively; finally, when the defense reserves are exhausted and the changes in the body exceed a certain critical level, there begins the phase of exhaustion -- irreversible changes build up which may lead to the death of the body [28, 49].

If the energy of the microwave action is correlated with the energy processes in the body itself, then we are dealing with the energy-information interactions. The energy aspect of this action consists in the transformation of the energy of electromagnetis field into other types of energy through the mechanisms discussed in the preceding sections. The informational role of microwaves is as follows: the body "selects" the energy which it assimilates from the environment, adjusts itself for receiving it, transforming it into another form, and accumulating it in the appropriate systems and elements [30,31]. Even in transforming microwave energy into thermal energy, which is connected with an increase in the oscillatory motion of the molecules, the informational role of this factor consists in the following: SHF fields, in addition to the thermal effect, "impose" upon the molecules of the tissues a rhythm of oscillations which is not characteristic of them. The basis of this informational role is the property of coherence which is inherent in microwaves [29].

Finally, if the energy of the microwave action is much less than the energy processes caused by it in the body, then we can speak of informational interaction [29, 30]. In this case, the effect depends not on the energy of the acting factor, but on the information introduced by it into the body. The elements of the nervous system perceiving the electromagnetic signal mobilize the material and energy resources of the body and ensure the appropriate response of the body to the information signal. The perception of information is connected with the form and nature of the signal and is proportional to the logarithm of signal intensity. The length of the signal and, consequently, the total value of its energy (dose) does not play an essential role in the preception of information [31].

No special receptors perceiving microwaves have been detected. However, it has been shown that complete are extremely sensitive to the action of electromagnetic fields and that this sensitivity increases if the body is exposed repeatedly to the action of weak fields. Adey [41, 43] has shown that the rhythm assimilation response in mammals can be changed under the effect of electric gradients substantially smaller than those which appear during postsynaptic stimulation in the brain tissue and much smaller than those which appear on synaptic terminals when the mediator is released. In order to explain this phenomenon, the author proposes the concept of cooperative mechanisms of the brain tissue perceiving external and internal electric fields. This concept is based on the idea that not only the nervous elements participate in the processing of information in the nervous system, but also the interaction between them and the neurogliac cells surrounding them. The sensitive macromolecular system on the membrane surfaces of neurons (glycocalix) can ensure the transformation of the component of the extracellular field into transmembrane effects ensuring the changes of intracellular potential at the expense of conformational rearrangement of macromolecules in the binding section of the membrane. The ability of binding potassium ions with polyanions of glycocalix is a cooperative process, since weak changes at one point of the initial macromolecular conformation cause changes at considerable distances [41]. It has been shown that SHF irradiation of an isolated brain placed in Ringer's solution containing $^{45}Ca^{2+}$ for 30 minutes causes an increase (in comparison with the control) in the yield of calcium from the cortex at modulation frequencies from 9 to 20 Hz. There is practically no increase in the calcium yield outside this frequency range. Adey's hypothesis may be considered as the application to neurophysiology of the thesis well known from the information theory about the intensification of sensitivity of physical systems to electromagnetic signals during spatial and temporal summation of signals [30, 31].

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The published data discussed above make it possible to conclude that, for effective utilization of microwaves in biology, medicine, and agriculture, as well as for revealing the degree of unfavorable effect of this factor on living organisms, it is necessary to conduct studies at all levels of organization of living systems: body, organ, cellular, subcellular, and molecular levels. To achieve this, it is necessary to conduct further studies on the effects of microwaves on the structure and functions of biological membranes and properties of artificial membranes, as well as to develop radio-spectroscopic methods of studies of biological membranes and investigate the role of hydrophobic interactions in the stabilization of their structure.

Bibliography

1. Borovyagin, V. L. "Cell Membranes," BIOFIZIKA [Biophysics], 1971, Vol 16, No 4

2. Vol'kenshteyn, M. V. "Molekuly i zhizn'" [Molecules and Life], Moscow, Nauka, 1965

3. "Problems of High-Frequency, Ultrahigh-Frequency, and Superhigh-Frequency Electrotherapy," TR TSENTR N-I IN-TA KURORTOLOGII I FIZIOTERAPTI [Transactions of the Central Scientific Research Institute of Health Resorts and Physiotherapy], 1971, Vol 17

4. Gay, A.; Lemann, Yu., and Stounbridzh, Yu. "Application of Electromagnetic Energy in Therapy," TR IN-TA INZHENEROV PO ELEKTRONIKE I RADIOELEKTRONIKE [Transactions of the Institute of Electronics and Radioelectronics Engineers], (translated from English), 1974, Vol 62, No 1

5. "Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot" [Labor Hygiene and Biological Effects of Radio-Frequency Waves], Collected Materials of the Third All-Union Symposium, 24-28 June 1968, Moscow 1968

6. "Gigiyene truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot." Collected Materials of the Fourth All-Union Symposium, 17-19 Ocrober 1972, Moscow 1972

7. Zhuravlev, A. I.; Tsvylev, O. P.; and Zubkova, S. M. "Spontaneous Endogenic Superweak Luminescence of Rats' Liver Mitochondria under the Conditions of Normal Metabolism," BIOFIZIKA, 1973, Vol 18, No 6

8. Zolotukhin, A. N.; Makukhin, V. N.; Nesterenko, M. T.; and Chistyakov, V. V. "Effects of Electromagnetic Radiation on Biological Objects and Physical Principles of Protection Against It," ZARUBEZHNAYA ELEKTRONIKA [Electronics Abroad], 1975, No 1

9. Zubkova, S. M. "Response of the Excitable Systems of Paramecia to Microwave Irradiation," Candidate's Dissertation, Moscow, 1967

10. Zubkova, S. M. "On the Mechanism of Microwave Action on Biological Membranes," TR TSENTR N-I IN-TA KURORTOLOGII I FIZIOTERAPII, 1976, Vol 32

11. Ismailov, E. Sh. "On the Effects of Microwaves on Opalina ranarum," Candidate's Dissertation, Leningrad, 1967

12. Ismailov, E. Sh. "On the Effects of Microwaves on the Nervous System," Theses of Reports of the All-Union Conference on the Problems of Biophysical Neurodynamics and General Biophysics, Leningrad, 1969

13. Ismailov, E. Sh. "On the Mechanism of the Action of Microwaves on the Permeability of Erythrocytes for Potassium and Sodium Ions," BIOL NAUKI [Biological Sciences], 1971, No 3

14. Ismailov, E. Sh. "Changes in the Permeability of Erythrocyte Membranes under the Effect of Microwaves and Its Mechanisms," IV International Biophysics Congress, Theses of Section Reports, Vol 4, Moscow, 1972

15. Ismailov, E. Sh. "On the Mechanism of the Action of Microwaves on the Permeability of Human Erythrocytes," in the Collection: "Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot," Moscow, 1972

16. Ismailov, E. Sh. "On the Problem of Physiochemical Effects of Microwaves on Biomembranes," "Biofizicheskiye aspekty zagryazneniya biosfery" [Biophysical Aspects of Biosphere Contamination], Symposium 5-8 June 1973, Moscow, Nauka, 1973

17. Ismailov, E. Sh. "Infrared Spectra of Erythrocyte Shadows in the Region of Amide I and Amide II Bands During Microwave Irradiation," BIOFIZIKA, 1976, Vol 21, No 5

18. Ismailov, E. Sh.; Bukarov, N. M.; and Sheripov, A. M. "On the Effects of Microwave Irradiation of Seeds on the Development of Corn," "Biofizika rasteniy" [Plant Biophysics], Symposium 10-13 Sept 1974, Krasnodar, 1974

19. Kamenskiy, Yu. I. "Effects of Microwaves on the Functional State of a Nerve," BIOFIZIKA, 1964, Vol 9, No 6

20. Kamenskiy, Yu. I. "Effects of Microwave Energy Dosage on the Parameters of a Nervous Impulse," in the Collection: "Gigiyena truda i biologicheskoye deystviye electromagnitnykh voln radiochastot," Moscow, 1968

21. Konev, S. V.; Aksentsev, S. L.; and Chernitskiy, Ye. A. "Kooperativnyye perekhody belkov v kletke" [Cooperative Transition of Proteins in a Cell], Minsk, 1970

22. Koreneva, L. G., and Gayduk, V. I. "On the Possibility of Resonance Effects of SHF Oscillations on Hemoglobin," DOKLADY AN SSSR, Biology Series, 1970, Vol 193, No 2

23. Manoylov, V. Ye., and Manoylov, Ye. Ye. "Effects of Microradiowaves on Some Hemoproteins," TR LENINGRADSK KHIM-FARM IN-TA [Transactions of the Leningrad Chemopharmaceutic Institute], 1967, Vol 20, No 1

24. Minin, B. A. "SVCh i bezopasnost' cheloveka" [SHF and Human Safety], Moscow, 1974

25. Mirutenko, V.I., and Bogach, P. G. "Effects of an SHF Electromagnetic Field on the Membrane Potential of Nerve Cells of Isolated Ganglia of the Mollusk Planorbis corneus," in the Collection: "Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot," Moscow, 1972

26. Obrosov, A. N.; Krylov, N. P.; Pertsov, A. I.; et al. "Some Results and Goals of the Institutes of Health Resorts and Physiotherapy in Connection with the Development of Problems of Application of Physical Factors for Preventive and Therapeutic Purposes," VOPR KURORTOLOGII I FIZIOTERAPII [Problems of Health Resorts and Physiotherapy] 1969, Vol 14

27. Polikar, A. "Poverkhnost' kletki i yeye mikrosreda" [Cell Surface and Its Micromedium], Moscow, Mir, 1975

28. Presman, A. S. "Effects of Microwaves on Living Bodies and Biological Structures," USPEKHI FIZ NAUK [Progress of Physical Sciences], 1965, Vol 86, No 2

29. Presman, A. S. "Elektromagnitnyye polya i zhivaya prioda" [Electromagnetic Fields and Animate Nature], Moscow, Nauka, 1968

30. Presman, A. S. "Elektromagnitnyye pola v biosfere" [Electromagnetic Fields in the Biosphere], Moscow, Znaniye, 1971

31. Presman, A. S. "Cosmos-Electromagnetic Fields-Biosphere-Body," in the Collection: Fiziko-matematicheskiye i biologicheskiye problemy deystviya elektromagnitnykh poley i ionizatsii vozdukha" [Physicomathematicaland Biological Problems of the Effects of Electromagnetic Fields and the Ionization of the Air," Vol 1, Moscow, Nauka, 1975

32. Sudakov, K. V., and Antimoniy, G. D. "Central Action Mechanisms of Electromagnetic Fields," USP FIZIOL NAUK [Progress of Physiological Sciences], 1973, Vol 4, No 2

33. Tolgskaya, M. S., and Gordon, Z. B. "Morfologicheskiye izmeneniya pri deystvii elektromagnitnykh voln radiochastot" [Morphological Changes under the Effect of Electromagnetic Radio-Frequency Waves], Moscow, Meditsina, 1971

34. Tyagin, N. V. "Klinicheskiye aspekty oblucheniy SVCh-diapazona" [Clinical Aspects of SHF-Range Irradiation], Leningrad, 1971

35. Kharvey, A. F. "Tekhnika sverkhvysokikh chastot" [Superhigh-Frequency Engineering], Vols 1-2, Moscow 1965

36. "Khimiya belka" [Protein Chemistry], Moscow, Mir, 1969

37. Kholodov, Yu. A. "Responses of the Nervous System to Electromagnetic Fields," in the Collection: "Fiziko-matematicheskiye i biologicheskiye problemy deystviya elektromagnitnykh poley i ionizatsii vozdukha," Vol 2, Moscow, Nauka, 1975

38. Schwan, H. "SVCh-biofizika" [SHF Biophysics], Vol 3, Moscow, Mir, 1971

39. Shnol', S. E. "Conformational Oscillations of Macromolecules," in the Book: "Kolebatel'nyye protsessy v biologicheskikh i khimicheskikh sistemakh" [Oscillatory Processes in Biological and Chemical Systems], Moscow, Nauka, 1967

40. Shtemler, V. M. "Studies on Some Aspects of the Mechanism of the Biological Effect of Microwaves," Candidate's Dissertation, Moscow, 1974

41. Adey, W. R. "Cooperative Mechanisms of the Perception of External and Internal Electric Fields of the Brain Tissue," FIZIOLOGIYA CHELOVEKA [Physiology of Man], 1975, Vol 1, No 1

43. Bawin, S. M.; Kaczmarek, L. K.; and Adey, W. R. "Effects of Modulated VHF Fields on Central Nervous System," ANN NEW YORK ACAD SCI, 1975, Vol 247, p 74

44. "BiologicalEffects of Nonionizing Radiation," NEW YORK ACAD SCI, 1975, Vol 247

45. Cleary, S. F. "Considerations in the Evaluation of the Biological Effects of Exposure to Microwave Radiation," AMER INDUSTR HYG ASS JOURN, 1970, Vol 31, No 1

42. Baranski, S,; Szmigielski, S.; and Monota, Y. "Effects of Microwave Irradiation in vitro on Cell Membrane Permeability," In: Biologic Effects and Health Hazards of Microwave Radiation," Warsaw, 1974

46. Conference on the Biological Effects of Nonionizing Radiation. Abstracts, New York, 1974

47. Deichmann, W.; Stephens, F.; Keplinger, M.; and Lamp, K. "Acute Effects of Microwave Radiation on Experimental Animals (2400 Mc)," JOURN OCCUP MED, 1959, No 1, p 369

48. Grant, E. H.; Jillinger, K. H.; Servantic, B.; and Szmigielski, S. "Session c. Effects of Microwave Radiation at the Cellular and Molecular Level," In: Biologic Effects and Health Hazards of Microwave Radiation," Warsaw, 1974

49. Michaelson, S.; Thomson, R.; and Howland, J. "Tolerance of Dogs to Microwave Exposure under Various Conditions," INDUSTR MED SURG, 1961, Vol 30, p 298

50. Schaefer, H., and Schwan, H. P. "The Question of Selective Heating of Small Particles in the Ultrashort Wave Condensor Field," ANN PHYSIC, 1943, Vol 43, p 99

51. Schaefer, H., and Schwan, H. P. "The Questions of Selective Heating of Single Cells in Biological Tissue with Ultrashort Waves," STRAHLENTHERAPIE, 1947, Vol 77, p 123

52. Schwan, H. P. "Biophysics of Diathermy," In: "Therapeutic Heat and Cold," Baltimore, Maryland, 1965

53. Schwan, H. P. "Microwave Radiation: Biophysical Considerations and Standards Criteria," IEEE Trans Biomed Engineer, 1972, Vol 19, No 4

54. Schwan, H. P. "Principles of Interaction of Microwave Fields at the Cellular and Molecular Level," In: Biologic Effects and Health Hazards of Microwave Radiation," Warsaw, 1974

55. Singer, S. Y. "The Molecular Organization of Membranes," AM REV BIOCHEM, 1974, Vol 43, p 305

56. Spanner, D. C. "On the Minute Size of Mitochondria," JOURN EXP BOT, 1959, Vol 10, No 29

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EFFECTS OF ELECTROMAGNETIC WAVES OF THE MILLIMETRIC RANGE ON THE ENERGY METABOLISM OF LIVER MITOCHONDRIA

Moscow BIOLOGICHESKIYE NAUKI in Russian No 6, 1977 pp 133-134

[Article by N. P. Zalyubovskaya, R. I. Kiselev, and L. N. Turchaninova]

[Text] In order to reveal the regularities of energy metabolism during irradiation with electromagnetic waves of the millimetric range, we studied oxidizing and energy characteristics of mitochondria isolated from the livers of the Wistar-line rats.

The animals were irradiated with a specialized unit which included an LOV [backward-wave tube]-type oscillator working within the wave range of 8.0-5.3 mm. The irradiation of the animals was done in an integrating resonator on a wave of 6.50 mm at a power flux density of 1 mW/cm^2 ten minutes daily in the course of 30 days. Liver mitochondria were isolated by means of centrifugation in a medium containing 0.25 M saccharose and 1 mM EDTA [ethylenediaminetetra-acetate] (pH 7.4). After removing EDTA by washing, mitochondria were suspended in 0.25 M saccharose and kept on ice. The oxygen consumption rate was registered polarographically by means of a rotating platinum electrode.

The energy metabolism of the mitochondria was studied in the dynamics of irradiation of the animals with millimetric waves. The obtained results indicated that in the course of the first five days of the irradiation of the animals, the functional activity of the liver mitochondria in various metabolic states did not change in comparison with the control (unexposed animals). On the tenth day of irradiation, the oxygen consumption rate of the mitochondria in the active phosphorylating state lowered, and the respiration rate decreased after the exhaustion of the reserves of ADP [adenosine diphosphate] ($P < 0.01$). As the irradiation time increased, the maximum inhibition of the energy metabolism of the mitochondria was observed on the twentieth day of exposure to millimetric waves. By this time, respiration intensity decreased by 1.4 times in comparison with the control under the effect of ATP [adenosine triphosphate]. This indicated that the ability for phosphorylation conjugated with oxidation decreased in the mitochondria of the animals irradiated with electromagnetic waves of the millimetric range, which was also confirmed by the lower values of the respiratory coefficient. By the twentieth day of the irradiation of the animals, the degree of the consumption of ADP by the mitochondria decreased by 42 percent, the reaction of the mitochondria to the addition of DNP [dinitrophenol] weakened by 1.3 , times, and the phosphorylating activity lowered in comparison with the mitochondria of unexposed animals. The phosphorylation process in the livers of exposed animals changed more than the oxidation process. By the thirtieth day, the energy metabolism in the irradiated animals was normalized, which can be evaluated as a compensatory-adaptive reaction of their bodies to the action of waves of the millimetric range.

Thus, as a result of the irradiation of animals with electromagnetic waves of the millimetric range, the oxidative and energy characteristics of liver mitochondria change, and the conjugation of the processes of oxidative phosphorylation lowers. The decrease in the oxygen consumption rate in a liver mitochondria could be the result of the inhibition of electron transfer in the same section of the respiratory system where phosphorylation was disturbed. When ADP is added, the respiration rate lowers more than the respiration rate after the exhaustion of ADP or against the background of the substrate because these rates are regulated also by the phosphate potential.

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EFFECTS OF ELECTROMAGNETIC ENERGY OF INDUSTRIAL FREQUENCY ON THE HUMAN AND ANIMAL NERVOUS SYSTEM

Kiev VRACHEBNOYE DELO in Russian No 6, 1977 pp 128-131

[Article by Candidates of Medical Sciences V. M. Popovich and I. P. Kozyarin, Laboratory of Electric and Electromagnetic Factors of the Environment (Director -- Doctor of Medical Sciences Yu. D. Dumanskiy), Kiev Scientific Research Institute of General and Communal Hygiene]

[Text] The leading role in the creation of the material and technical basis of communism in our country belongs to electrification of industry, agriculture, transportation, and the everyday life of the urban and rural population. In this connection, the Soviet Union is completing the construction of unified power systems of the country employing electric power transmission lines (LEP) of superhigh voltage (330, 500, 750 kV and over). This creates voltages of electromagnetic fields of industrial frequency (EMPPCh) in the working zones which reach a level of 12-17 kV/m and have unfavorable effects on the human organism exposed to them.

A number of researchers (F. P. Petrov, 1953; N. A. Solov'yev, 1963; V. I. Ban'kov, 1972; Yu. A. Kholodov, 1975) state that EMPPCh, just as electromagnetic fields of radio frequencies, have an unfavorable effect on functional state of the nervous system. This is also indicated by research materials of the Leningrad Institute of Labor Protection which showed that people exposed to EMPPCh were found to have, primarily, changes in the nervous system.

We made it our goal to study the biological effect of EMPPCh of various intensities on the functional state of the nervous system in an experiment on animals exposed to it daily for two hours in a short period of time.

White male rats (130) served as an experimental model. They were placed in dielectric cages with modeled electric field with a frequency of 50 Hz created by transformers NOM-10. The animals of the first group served as a control, and the animals of the second group were exposed daily for two hours in the course of four months to the action of a EMPPCh with an intensity of 1 kV/m, animals of the third group -- 2 kV/m, animals of the fourth group -- 4 kV/m, animals of the fifth group -- 7 kV/m, and animals of the sixth group -- 15 kV/m.

In order to judge the biological effect of irradiation on the nervous system, we made a monthly study during the experiment of the summary-threshold index (according to S. V. Speranskiy, 1965), the time of the latent period of the unconditioned reflex, chronaxie of antagonist muscles of the shin, and the activity of the blood cholinesterase (according to Khestrin).

The determination of the summary-threshold index (SPP) and the chronaxie of antagonist muscles was done by means of a universal electric impulse generator (UEI-1). The time of the latent period of the reflex was determined by means of a chronoreflexometer made by the experimental shops of the Leningrad Institute for the Advanced Training of Physicians. In order to obtain average values, each measurement was repeated four-five times and the average was calculated. The studies were done before the beginning of the experiment, after each month of exposure to EMPPCh, and 30 days after the termination of irradiation (restoration period).

The dynamic observation of the functional state of the nervous system in the experimental animals indicated that in animals of the fifth and sixth groups (E = 7 and 15 kV/m) beginning with the first month and to the end of the experiment, there was a definite increase in the SPP and the time of the latent period of the reflex in comparison with the animals in the control group (Table).

Table

Показатели (1)	(6) Статистические показатели	(7) Группы животных					
		первая (контроль) (8)	(9) вторая (1 кВ/м)	(10) третья (2 кВ/м)	(11) четвертая (4 кВ/м)	(12) пятая (7 кВ/м)	(13) шестая (15 кВ/м)
(2) СПП (в вольтах)	M±m	11,7 0,5	11,2 0,3	11,7 0,5	12,0 0,4	17,3 * 0,2	19,1 * 0,1
(3) Время латентного периода безусловного рефлекса (в миллисекундах)	M±m	51,0 1,7	55,1 1,5	52,8 1,3	52,3 1,7	67,0 * 1,5	69,6 * 1,9
(4) Соотношение хронаксии мышц — антагонистов голени (разгиб./сгибател.)	M±m	1,9 0,2	1,6 0,2	1,6 0,2	1,6 0,1	0,5 * 0,08	0,4 * 0,04
(5) Активность холинэстеразы крови (γ/мин.)	M±m	130,8 3,3	127,3 6,0	128,6 5,8	128,6 5,8	134,5 4,1	150,2 * 6,5

Note: *-P $<$ 0.05

Key:
1. Indexes
2. SPP (in volts)
3. Time of the latent period of the unconditioned reflex (in milliseconds)
4. Ratio of the chronaxie of muscles -- shin antagonists (extensor/flexor)
5. Blood cholinesterase activity (γ /min)
6. Statistical indexes
7. Groups of animals
8. First (control)

Table (Continued)
Key: 9. Second (1 kV/m)
10. Third (2 kV/m)
11. Fourth (4 kV/m)
12. Fifth (7 kV/m)
13. Sixth (15 kV/m)

In order to evaluate the state of the excitability of the peripheral and central nervous system, we used the simplest and most sensitive method of motor chronaxie.

In this experiment, we studied the chronaxie of antagonist muscles of the shin and calculated the coefficient of the extensor-flexor chronaxie ratio. The lengthening of the chronaxie indicates the lowering of the excitability of the central nervous system, and its shortening indicates an increase in excitability.

In the animals of the fifth and the sixth groups, a reliable decrease in the antagonist chronaxie ratio was revealed since the end of the second (group 6) and the third (group 5) months of exposure to EMPPCh, which progressed after that. At first, the decrease in the chronaxie ratio of the muscles occurred, chiefly, at the expense of the increase in the chronaxie of the flexors, but later, along with an increase in the chronaxie of the flexors, we registered its decrease in the extensors, which led to a large decrease of this index.

Lapik (author of the chronaxie theory) mentions that, under normal conditions, differences in the values of chronaxies of antagonists are determined by the influence of the red nuclei of the brain -- "subordination centers." When the inhibitary process appears in the central nervous system, the subordination effect of the central nervous system on the periphery is disturbed, as a result of which definite shifts are observed in the chronaxie ratio of antagonist muscles leading to the leveling of the chronaxies or to a decrease in their ratio coefficient (in normal conditions, the coefficient of the ratio of extensors to flexors is greater than 1.0).

Thus, the increase in the SPP, the time of the latent period of the unconditioned reflex, and the changes in the chronaxie ratio of antagonist muscles of the shin in the animals of the fifth and sixth groups (E = 7 and 15 kV/m) were, evidently, connected with the disturbance of dynamic balance between the processes of excitation and inhibition in the cerebral cortex, the latter being dominant (Figure 1).

The activity of cholinesterase of the blood and organs is one of the highly sensitive indexes of the influence of environmental factors on the organism. A number of researchers believe that the cholinesterase activity characterizes indirectly the functional state of the central nervous system. With this in mind, we considered it expedient to use the method of determining the total activity of the true and false cholinesterase in the blood by means of the photocolorimetric method according to Khestrin.

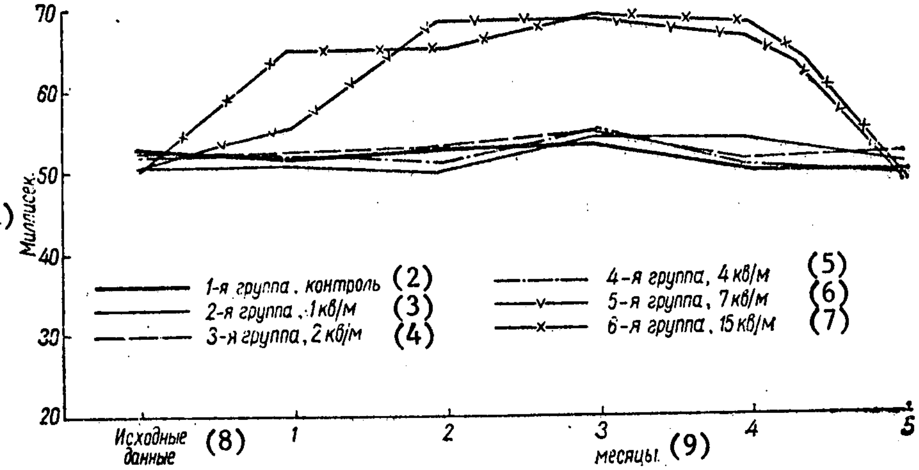

Figure 1. The time of the latent period of the unconditioned reflex in animals under the effect of an electromagnetic field of industrial frequency (in milliseconds).

Key:
1. Milliseconds
2. First group, control
3. Second group, 1 kV/m
4. Third group, 2 kV/m
5. Fourth group, 4 kV/m
6. Fifth group, 7 kV/m
7. Sixth group, 15 kV/m
8. Initial data
9. Months

The results of our observations showed that under the effect of EMPPCh there were changes in the activity of the cholinesterase of the blood whose nature depended on the level of the field intensity and length of exposure. For example, in the animals of the fifth group (E = 7 kV/m), in the course of the first two months of exposure to EMPPCh we observed a definite increase in the activity of the cholinesterase of the blood with subsequent decrease of its activity to values equal to those in the animals of the control group (in the third and fourth months of the experiment), which, evidently, was connected with the development of adaptation-compensation reactions in the organisms of the animals. In the animals of the sixth group (E = 15 kV/m), we observed a steady increase in the activity of the cholinesterase of the blood in comparison with the control group from the first months and to the end of the experiment. The increase in this blood enzyme in the animals of the fifth and sixth groups could indicate a disturbance in the biochemical homeostasis which ensures a steady progress of nervous processes. All of the changes described above were reversible, and were restored in the course of 30 days after the termination of exposure.

The results of the experimental studies indicate that, for all studied indexes of the functional state of the nervous system, the threshold level of the field is 7 kV/m, and its subliminal value is within the limits of 4-7 kV/m.

These studies were supplemented with observations of 10 healthy people from 23 to 47 years of age (5 men and 5 women), who in the course of 30 days, two hours daily, were exposed to an electric field of 5 kV/m created by a superhigh-voltage line of 330 kV under natural conditions. The study of the functional state of the nervous system (mobility of nervous processes in the central nervous system) by studying the volume of operative memory and ability for concentrating the attention, studies of the bioelectric activity of the cerebral cortex by the method of electroencephalography did not make it possible to establish any substantial changes in comparison with the initial data during the observation period.

The second series of observations was conducted on 24 persons (12 men and 12 women) of the same ages, who were divided into two groups (6 men and 6 women in each). The first group was exposed in the course of six days to an EMPPCh of 12 kV/m, three times daily for 30 minutes each time with an one hour interval between the exposures to the field, and the second group was in the same conditions for six days with a field intensity level of 15 kV/m.

The volunteers exposed to an EMPPCh with a field level of 12 kV/m did not complain about the state of their health, and no substantial changes in the indexes under study were observed in them. When the subjects were exposed to electromagnetic energy with a field intensity of 15 kV/m, most of them felt heavy and had a slight pain in the temporal and occipital regions of the head on the third day, with subsequent complaints about transient headaches, fatigue, and irritability. On the second day of exposure, changes in the generated potentials to light stimulation were observed in most of the subjects. For example, the amplitude of the assimilable rhythm at a frequency of 8 flickers per second increased on the average by 11.2 percent in comparison with the initial value. In some persons, the amplitude of the biopotentials during the exposure to rhythmic light stimuli with a frequency of 12 Hz increased by 50.7 percent.

Thus, an electromagnetic field of industrial frequency of 15 kV/m increases the lability of the neurons of the visual centers of the cortex, because the higher the lability of the tissue, the finer changes of the environment it perceives. Moreover, the increase in the amplitude of the assimilable rhythm of light flickers indicates an abnormal increase of the excitability of the nervous tissue.

We believe that, in order to prevent the unfavorable effects of EMPPCh, it is necessary to develop maximum permissible levels (PDU) of the intensity of the electromagnetic field of 50 Hz for the conditions of populated areas.

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METABOLISM AND DISTRIBUTION OF IRON, COPPER, MOLYBDENUM, MANGANESE, AND NICKEL IN THE ORGANS OF A BODY EXPOSED TO INDUSTRIAL AND SUPERHIGH FREQUENCY ELECTROMAGNETIC FIELDS

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[Text] A number of studies have shown that one of the main features of the biological action of electromagnetic fields (EMF) is alteration of the functional states of various divisions of the nervous system which leads, directly or indirectly, to disturbance of the body's normal functions. This is why changes in the functional state of the nervous system are recorded as one of the earliest and dominant reactions of the body in response to EMF of both industrial and superhigh frequency (IF and SHF) (4,6). At the same time it has been established (3) that changes in the functional state of the central and autonomic nervous systems, proceeding in different directions, have a pronounced influence on metabolism and distribution of trace elements among the organs, especially the transitory metals present in the active centers of many enzymes.

These circumstances served as the grounds for this work, the goal of which was to reveal specific features of the metabolism and distribution of copper, iron, molybdenum, manganese, and nickel in the organs of a body exposed to EMF of different frequencies and intensities.

Unisexual white male Wistar strain rats with an initial weight of 120±10 gm served as the experimental biological model. The animals were fed starch-casein feed recommended by the USSR Academy of Medical Sciences Institute of Nutrition and an appropriate salt mixture. Three series of experiments were conducted.

In series I we modeled the possible radiation the public would experience from an IF field created by high voltage power transmission lines. With this purpose the animals were placed in special dielectric cages subjected to the 50 Hz modeled electric field (EF) generated by high voltage oil transformers. There were 25 rats in each experimental group. Animals in group 1 (control) were not irradiated, group 2 was irradiated by a 7 kv/m EF, group 3 was exposed to 12 kv/m, and group 4 was exposed to 15 kv/m. Animals were irradiated 30 minutes daily for 4 months. In series II the rats were irradiated 2 hours daily for 4 months. Animals in group 1 served as controls. The other groups were irradiated by EF of the following intensities: Group 2--1 kv/m, group 3--2 kv/m, group 4--4 kv/m, group 5--7 kv/m, group 6--15 kv/m. The exposure times were selected after preliminary natural examination, which indicated that people passing beneath EF lines or working near them could be arbitrarily divided into two groups--those subjected to EF for up to 30 minutes and those subjected for up to 2 hours per day.

In series III the rats were irradiated by superhigh frequency energy daily, 8 hours per day for 4 months. A magnetron oscillator working at a frequency of 2,370 MHz served as the microwave source. The energy flux density (EFD) was monitored by a Medik-1 instrument. The rest were irradiated in special echoless cages making uniform distribution of the EMF possible. Animals in group 1 served as controls, those of group 2 were irradiated by a 10 $\mu w/cm^2$ EFD, those of group 3 were exposed to 100 $\mu w/cm^2$, and those of group 4 were exposed to 1,000 $\mu w/cm^2$.

Before the conclusion of the experiment the rats were placed in special metabolic cages in which urine and feces were collected for 5 days to determine the trace element balance. At the end of the experiment the animals were killed, and the tissue trace element concentrations were determined by a quantitative spectrographic method (5). The obtained data were subjected to variational statistical treatment, in which differences were assumed to be significant at $P<0.05$. Significant differences in the characteristics for experimental and control rats are indicated by asterisks in the tables.

As we can see from Figure 1*A*, the data of series I show that as the intensity of the EF rises the concentration of copper in the urine and feces of irradiated animals decreases, and a correspondingly larger quantity of this element accumulates in the body (Figure 2*A*), the difference from the controls being significant beginning with group 3. Redistribution of copper among the organs after irradiation is interesting. We can see from Table 1 that the level of copper declines in its main source of deposition--the liver, and that it increases in all "actuating" organs and in blood. Growth in the activity of the copper-containing protein ceroluplasmin in blood serum in the course of the experiment also attested to intensified withdrawal of copper from the liver. Thus its activity in the blood of group 1 rats was 35.9±1.9 a.u. [arbitrary units], it was 37.6±2.1 a.u. for group 2 rats, 41.2±1.8 a.u. for group 3 rats ($P<0.05$), and 46.0±1.3 a.u. for group 4 rats ($P<0.05$). Thus significant changes in the concentration of copper in urine and in some organs (the kidneys, the spleen, the myocardium) were revealed even among animals subjected to a 7 kv/m EF, but significant changes occurred in almost all organs, in the carcass, and in the blood (disturbance of Cu-homeostasis) only among those animals subjected to 12 and 15 kv/m. Changes in nickel metabolism after irradiation of the animals are identical to changes in copper metabolism, and for this reason they are not cited here.

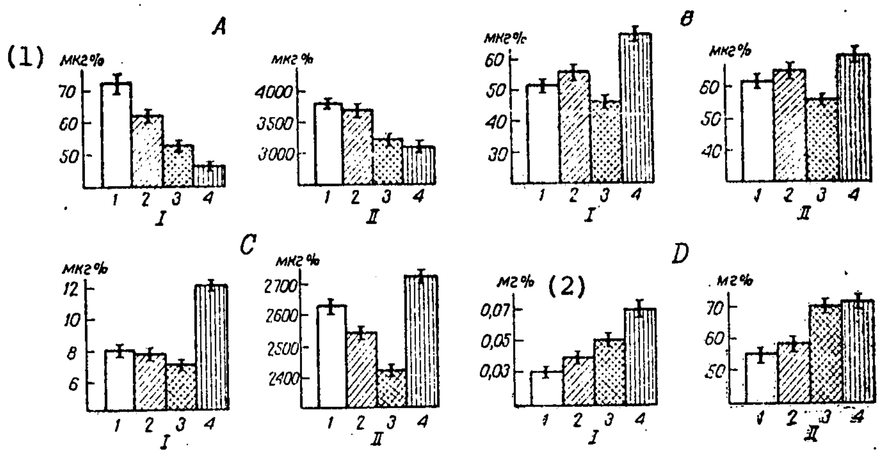

Figure 1. Concentration of Trace Elements in Urine (*I*), and Feces (*II*) of Rats Exposed to an IFEF: *A*--Copper; *B*--molybdenum; *C*--manganese; *D*--iron; here and in figures 2-4, *1-4* represent the animal groups.

Key:

1. µg-%
2. mg-%

Inasmuch as we also studied the state of the nervous system of the animals in the dynamics of the experiment, we were able to note that animals in group 2 exhibited insignificant changes in the summational-threshold characteristic, latent reflex time, and other indices, while rats in groups 3 and 4 exhibited pronounced changes.

Let us now go on to an examination of the metabolism of molybdenum, which in many ways is a physiological antagonist of copper (2,10).

Elimination of molybdenum with urine and feces increased among irradiated animals (Figure 1*B*), owing to which its level decreased in individual organs (see Table 1) and in the body as a whole (Figure 2*B*). Its concentration increased only in kidney tissue, which is usually observed when forced elimination of this trace element with urine occurs. The copper-molybdenum index increase in the blood and tissues of most organs of irradiated rats. Thus it was 24:1 for the blood of group 1 and 2 animals, 31:1 for group 3 rats, and 40:1 for group 4 rats; the figures for brain tissue were, correspondingly, 11.5, 13, 16, and 21. There are grounds for suggesting that growth in the copper quantity and the copper-molybdenum index for tissues is associated with the body's adaptive reactions to extreme environmental factors (11). Accumulating predominantly in cell mitochondria, copper participates in the oxidative processes proceeding in the organelles.

Negative shifts in iron metabolism were observed among irradiated animals: The concentration of iron increased in feces and urine (Figure 1*D*) and decreased in its most important source of deposition--the liver, and in

Table 1. Concentration of Copper and Molybdenum in Rat Tissues After 4 Months of Exposure to IFEF (μg-% Per Wet Weight of Organ or Tissue, $\overline{X} \pm S\overline{x}$).

Объект исследования (1)	(2) Медь				(3) Молибден			
	контроль (4)	7 кВ/м (5)	12 кВ/м (6)	15 кВ/м (7)	контроль (4)	7 кВ/м (5)	12 кВ/м (6)	15 кВ/м (7)
(8) Печень	721,3 33,3	699,4 31,9	631,2 21,5	586,5* 23,4	41,2 2,9	35,2 2,1	32,3* 1,6	29,4** 1,2
(9) Почки	203,2 10,1	250,0* 10,0	292,3** 14,6	347,2** 17,4	23,4 1,5	24,6 1,2	29,4* 1,1	32,4** 1,3
(10) Селезенка	45,3 1,8	57,2* 3,4	70,3** 2,8	128,5** 6,4	7,9 0,3	6,5* 0,3	3,8** 0,2	2,7** 0,1
(11) Головной мозг	163,9 11,5	168,7 10,1	171,0 6,8	201,6* 8,1	14,1 0,6	13,2 0,7	10,6** 0,4	9,7** 0,5
(12) Миокард	119,0 4,7	141,2* 7,0	153,3** 9,2	182,2** 9,1	3,3 0,1	3,2 0,2	2,9* 0,1	2,8** 0,1
(13) Мышцы (скелетные)	27,5 1,4	26,3 1,6	33,9* 1,7	39,1** 1,5	4,4 0,2	4,0 0,2	3,6* 0,1	3,5* 0,3
(14) Кожа	21,2 0,8	22,4 1,3	26,3* 1,6	28,4** 1,1	3,7 0,2	3,8 0,2	3,8 0,1	3,1* 0,1
(15) Кости (бедренные)	429,7 21,5	513,4 30,8	582,2** 23,3	591,4** 23,6	904,3 44,2	897,4 44,8	844,3 34,6	721,2* 28,8
(16) Зубцы (резцы)	254,4 15,2	292,3 17,5	321,3* 16,1	369,4** 18,5	785,2 24,9	778,4 44,5	713,5 22,8	684,2* 34,2
(17) Кровь	59,7 3,6	60,4 3,0	72,6* 2,9	75,2* 3,7	2,5 0,1	2,5 0,1	2,3 0,09	1,9** 0,07

* $P<0{,}05$.
** $P<0{,}01$.

Key:

1. Object of analysis
2. Copper
3. Molybdenum
4. Control
5. 7 kv/m
6. 12 kv/m
7. 15 kv/m
8. Liver
9. Kidneys
10. Spleen
11. Brain
12. Myocardium
13. Muscles (skeletal)
14. Skin
15. Bones (femurs)
16. Teeth (incisors)
17. Blood

bone marrow, a number of other organs, blood (Table 2), and in the entire carcass (Figure 2*C*). We determined the degree of saturation of blood serum transferrin with iron in the dynamics of the experiment.* This characteristic dropped among irradiated animals, and by the end of the experiment it was lower among animals in groups 3 and 4 than among control animals ($P<0.05$) (0.26±0.01 a.u. for controls, 0.24±0.01 a.u. for group 2

*Ceroluplasmin activity and saturation of blood serum transferrin by iron were determined colorimetrically (1).

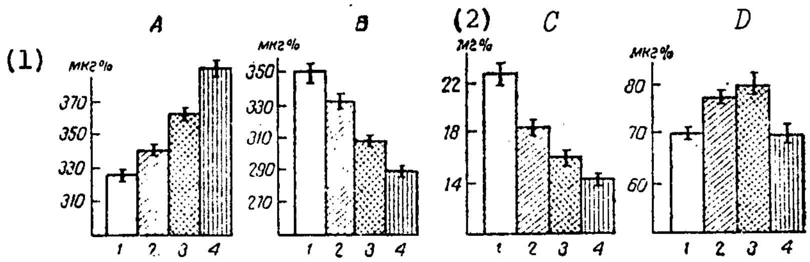

Figure 2. Concentration of Trace Elements in Animal Carcasses in Response to IFEF: *A*--Copper; *B*--molybdenum; *C*--iron; *D*--manganese.

Key:

1. µg-%
2. mg-%

Table 2. Concentration of Iron and Manganese in Rat Tissue After 4 Months of Exposure to IFEF ($\bar{X} \pm S\bar{x}$).

Объект исследования (1)	(2) Железо, мг%				(3) Марганец, мкг%			
	Контроль (4)	кВ/м (5)	12 кВ/м (6)	15 кВ/м (7)	Контроль (4)	7 кВ/м (5)	12 кВ/м (6)	15 кВ/м (7)
(8) Печень	33,1 2,3	29,5 1,8	23,9* 1,2	18,4** 0,7	131,9 7,9	131,9 6,6	166,1* 6.6	173,9** 6,9
(9) Почки	9,3 0,5	10,2 0,5	11,4* 0,7	12,5** 0,6	57,6 2,9	56,3 3,4	54,9 2,7	61,7 3,1
(10) Селезенка	14,6 0,8	15,7 0,6	15,1 0,6	15,8 0,6	7,3 0,3	10,8** 0,6	15,3** 0,7	7,6 0,3
(11) Головной мозг	14,2 0,8	13,2 0,7	12,5 0,7	11,2* 0,6	21,7 0,9	30,7** 1,2	36,8** 1,5	22,7 1,1
(12) Миокард	2,8 0,1	2,8 0,1	2,8 0,1	2,9 0,1	7,8 0,4	12,2** 0,6	23,7** 0,9	11,4** 0,6
(13) Мышцы (скелетные)	0,3 0,02	0,3 0,02	0,4 0,02	0,3 0,01	3,8 0,2	4,3 0,2	4,5* 0,1	4,7* 0,2
(14) Кожа	2,2 0,1	2,2 0,1	1,8 0,1	1,7** 0,07	5,5 0,3	6,1 0,2	12,9** 0,8	10,1** 0,5
(15) Кости (бедренные)	22,2 1,5	17,5* 1,0	15,2** 0,6	12,4** 0,6	139,8 7,8	120,4 9,7	110,4* 5,5	82,2** 4,9
(16) Костный мозг	11,4 0,7	9,1 0,9	7,1** 0,7	6,4** 0,4	—	—	—	—
(17) Кровь	32,9 1,2	30,4 2,1	27,4* 1,4	23,8** 1,2	2,3 0,1	2,3 0,1	2,4 0,09	2,4 0,1

* $P<0{,}05$.
** $P<0{,}01$.

Note: The concentration of iron and manganese is given in relation to organ or tissue wet weight.

Key:

1. Object of analysis
2. Iron, mg-%
3. Manganese, µg-%
4. Control
5. 7 kv/m
6. 12 kv/m
7. 15 kv/m
8. Liver
9. Kidneys
10. Spleen
11. Brain
12. Myocardium
13. Muscles (skeletal)
14. Skin
15. Bones (femurs)
16. Bone marrow
17. Blood

rats, 0.20±0.01 a.u. for group 3 rats, 0.16±0.015 a.u. for group 4 rats). According to (9) a decline in blood iron level combined with reduced saturation of transferrin by iron is observed when iron is chronically short in the body and when consumption of reserve iron (from its source of deposition) increases, as was noted in our experiment.

Change in the manganese balance of rats is unique. When rats are irradiated by 7 and 12 kv/m EF its elimination declines, as is the case with copper, but it rises dramatically with a 15 kv/m EF (Figure 1*C*). The manganese concentration follows this law in the carcass (Figure 2*D*) and in a number of organs--the spleen, brain, myocardium, and skin (see Table 2). Another interesting point is that the changes in response to an EF proceed in different directions in the two most important sources of manganese deposition--the liver and the bones: Its concentration declines in bones and grows in the liver. This is apparently why Mn-homeostasis is not disturbed.

In series II, involving longer daily irradiation, the direction of changes in trace element metabolism was identical to that noted in series I. However, significant shifts were observed with fields of lower intensity. We should emphasize that significant changes in the balance of all trace elements analyzed and in their distribution among the organs were detected even with a 2 kv/m IFEF, while the threshold of IFEF action upon the functional state of the nervous system (enlargement of the (SPP) and the reflex latent time, change in the antagonistic muscle chronaxie ratio) was between 4 and 7 kv/m.

The results of series III, in which the animals were subjected to superhigh frequency energy, are shown in figures 3 and 4 and in Table 3. They indicate that exposure of the white rat body to an SHF EMF changes the balance of all trace elements analyzed and their distribution among the organs. The directions of the changes are similar in many ways to those exhibited by rats exposed to IFEF: As the EFD increased, elimination of copper, manganese, and nickel decreased and elimination of iron increased. Correspondingly the distribution of trace elements among the organs changed (see Table 3). Initial shifts in metabolism of individual trace elements were revealed with even an extremely low EFD (10 $\mu w/cm^2$). The order of magnitude of the threshold of superhigh frequency energy action upon the state of the central nervous system is approximately the same (5 $\mu w/cm^2$) (8). However, pronounced changes in the distribution of all trace elements among the organs coupled with disturbance of their homeostasis were observed only among animals irradiated by EFD of 100 $\mu w/cm^2$ and higher.

The research showed that prolonged exposure of the body to IF and SHF EMF basically leads to shifts of identical directions in the balance of the trace elements analyzed and in their distribution among the organs. Basically these changes involve a decline in the concentrations of copper, manganese, and nickel in feces and urine, and an increase in their concentrations in most organs and in the entire animal carcass. We can hypothesize that these disturbances in trace element metabolism play a certain role in the

Table 3. Concentration of Trace Elements in Rat Tissues at the End of the Experiment After Exposure to an SHF Field.

Объект исследования (1)	(2) Группа крыс 1	2	3	4
(3) *Медь, мкг%*				
(4) Печень	446,8±12,3	416,5±10,4*	389,8±17,6*	331,1±15,3*
(5) Почки	479,2±25,4	405,9±19,6*	309,2±18,3*	398,2±18,7*
(6) Кости (бедренные)	237,7±12,8	226,8±15,3	266,5±20,8	277,7±25,3
(7) Головной мозг	198,0±13,5	198,0±15,3	233,6±11,1	298,2±28,4*
(8) Миокард	113,4±8,2	142,8±7,4*	189,2±17,9*	266,6±27,3*
(9) Кровь	56,2±4,4	66,0±5,7*	85,0±7,4*	74,0±4,5*
(10) *Молибден, мкг%*				
(4) Печень	58,9±3,2	57,8±2,9	47,9±3,1*	40,8±2,5*
(5) Почки	9,5±0,5	12,9±1,1*	15,2±1,4*	24,0±2,8*
(6) Кости (бедренные)	532,1±11,6	532,6±12,4	514,1±11,9	485,6±12,4*
(7) Головной мозг	9,8±0,3	8,9±0,24*	7,9±0,9*	5,9±0,6*
(8) Миокард	3,6±0,1	3,6±0,4	3,6±0,3	3,6±0,2
(9) Кровь	2,4±0,12	2,4±0,14	1,7±0,2*	1,4±0,14*
(11) *Железо, мг%*				
(4) Печень	23,7±1,0	28,5±1,7*	38,2±4,2*	57,6±4,7*
(5) Почки	19,6±2,1	24,0±1,9	33,9±2,7*	79,4±6,8*
(6) Кости (бедренные)	22,2±1,3	19,3±1,1	15,1±0,8*	10,3±1,6*
(7) Головной мозг	11,4±0,9	10,4±0,7	6,3±0,5*	2,9±0,3*
(8) Миокард	8,0±0,9	8,5±1,2	9,0±0,8	10,4±1,3
(12) Костный мозг	13,5±1,4	9,8±0,7*	8,1±0,9*	6,1±0,8*
(9) Кровь	42,8±3,1	37,4±2,0	31,2±2,6	21,2±2,2
(13) *Марганец, мкг%*				
(4) Печень	139,2±7,1	167,3±10,6*	221,3±14,7*	230,0±16,9*
(5) Почки	45,2±2,6	48,3±3,1	66,7±4,1*	70,3±3,1*
(6) Кости (бедренные)	71,3±3,6	63,2±4,7	60,5±3,9	55,2±2,6
(7) Головной мозг	22,0±0,8	24,1±1,5	23,7±1,2	24,8±0,9*
(8) Миокард	13,8±0,7	15,6±1,1	18,5±1,2*	20,3±1,2*
(9) Кровь	2,1±0,1	2,1±0,1	2,2±0,1	2,8±0,1*

* $P<0{,}05$.

Key:

1. Object of research
2. Rat group
3. Copper, μg-%
4. Liver
5. Kidneys
6. Bones (femurs)
7. Brain
8. Myocardium
9. Blood
10. Molybdenum, μg-%
11. Iron, mg-%
12. Bone marrow
13. Manganese, μg-%

body's adaptive reactions to the action of an EMF. In particular, irradiation of biological objects by an EMF intensifies free-radical processes, while transitory metals (nickel and copper for example) promote their normalization (7).

Iron behaves differently in irradiated rats. Its concentration grows in feces and urine, and it drops in most organs and in the entire carcass.

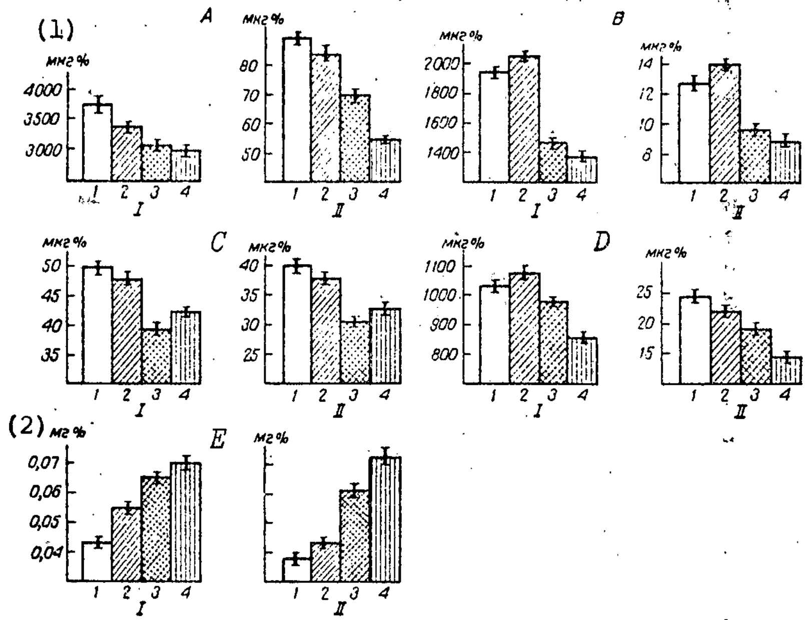

Figure 3. Concentration of Trace Elements in Feces (*I*) and Urine (*II*) of Rats Subjected to an SHF Field: *A*--Copper; *B*--molybdenum; *C*--manganese; *D*--nickel; *E*--iron.

Key:

1. μg-%   2. mg-%

Obviously the redistribution we have revealed in iron ions, participating in gas transport in the blood and existing as components of oxidative enzymes, and copper ions, which function in electron transport in the last stage of oxidative processes, plays a certain role in the mechanism behind metabolic and functional shifts occurring in the body in response to IF and SHF EMF.

We must not fail to lay special emphasis on the different effects irradiation has upon metabolism of copper and iron, as is also confirmed by the observations of S. M. Mints et al. (6). The directions of the shifts in metabolism of iron and copper were identical in all of our previous studies in which the body was exposed to other physical and chemical substances. The described changes in trace element metabolism depend on EMF intensity. Significant disturbances in trace element metabolism are revealed in individual organs when intensity is lower. At higher intensity such shifts are observed in almost all organs and in the body as a whole (the carcass), similar in direction but more pronounced; moreover the level of the trace element in blood almost always changes, indicating disturbance of biochemical homeostasis.

Are the described changes in trace element metabolism related to manifestations of the direct effect of an EMF on irradiated organs and tissues, or

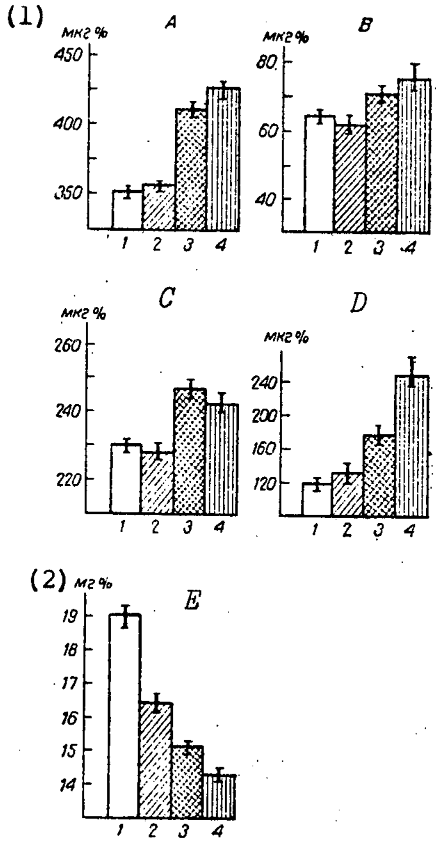

Figure 4. Concentration of Trace Elements in Animal Carcasses After Exposure to an SHF Field: *A*--Copper; *B*--manganese; *C*--molybdenum; *D*--nickel; *E*--iron.

Key:
1. µg-%
2. mg-%

are they the consequence of an indirect effect through the nervous system? Absence of a commonly accepted theory on the mechanisms behind biological action of an EMF permits only a hypothetical response to this question.

In general the qualitatively almost identical nature of changes in trace element metabolism among animals irradiated by EMF differing significantly in their physical characteristics indicates, most probably, that these changes are the consequence of disturbance of the functional state of the nervous system (that is, it indicates indirect action). Another argument in favor of this hypothesis is that the initial changes in trace element metabolism begin to be registered as a rule with EMF of the same intensities at which the initial shifts in nervous system function are observed (experimental series I and III). However, we cannot exclude the possibility that direct irradiation of tissues does have significance in addition to indirect action. After all, we were able to establish in series II (small intervals of a modeled IFEF) that changes are observed in trace element metabolism at a field intensity which does not elicit shifts in the functional state of the nervous system (2 kv/m). Hypotheses on the possible mechanisms behind primary interaction (at the molecular level) between EMF and biological tissues fully permit the suggestion that such fields have a direct action upon trace elements or their protein complexes (7).

Conclusions

1. The results of the experiments indicate the suitability of studying trace element metabolism in hygienic research on the effect of EMF of different frequency ranges upon the human and animal body, as well as in establishing the grounds for the appropriate maximum permissible levels.

2. Deeper study of the effects of an EMF on the trace element balance and exchange of trace elements among different organs is recommended. The subjects of research could include the specific features of the action of EMF of different ranges, the specific features of the trace element balance in people subjected to EMF in production conditions, the physiological significance of the observed shifts in the balance of trace elements and their distribution among the organs, and others.

BIBLIOGRAPHY

1. Babenko, G. A., "Mikroelementy v eksperimental'noy i klinicheskoy meditsine" (Trace Elements in Experimental and Clinical Medicine), Kiev, 1965.

2. Boynar, A. O., "Biologicheskaya rol' mikroelementov v organizme zhivotnykh i cheloveka" (The Biological Role of Trace Elements in the Body of Animals and Man), Moscow, 1960.

3. Gabovich, R. D., Mikhalyuk, I. A., and Fesenko, L. D., UKR. BIOKHIM. ZH., No 2, 1974, pp 227-231.

4. Gordon, Z. V., "Voprosy gigiyeny truda i biologicheskogo deystviya elektromagnitnykh poley sverkhvysokikh chastot" (Problems in Labor Hygiene and the Biological Action of Superhigh Frequency Electromagnetic Fields), Leningrad, 1966.

5. Zaydel', A. N., "Emissionnyy spektral'nyy analiz atomnykh materialov" (Emission Spectrum Analysis of Atomic Materials), Leningrad-Moscow, 1960.

6. Mints, S. M., et al., VOPR. KURORTOL., No 3, 1976, pp 44-46.

7. Chibrikin, V. M., et al., "Tezisy dokladov Vsesoyuznogo simpoziuma 'Fiziko-matematicheskiye i biologicheskiye problemy deystviya elektromagnitnykh poley i ionizatsii vozdukha'" (Abstracts of Reports at the All-Union Symposium "Physicomathematical and Biological Problems in the Action of Electromagnetic Fields and Ionization of Air"), Yalta, 1975, p 51.

8. Shutenko, O. I., "Hygienic Characteristics of SHF Electromagnetic Fields in the Conditions of Populated Areas," candidate dissertation abstract, Kiev, 1974.

9. Bruschke, G., "Der Eisenstoffwechsel," Dresden, 1964.

10. Seeling, M. S., AM. J. CLIN. NUTR., Vol 25, 1972, pp 1022-1037.

11. Uil'yams, D., (Williams, D. R.), "Metally zhizni" (The Metals of Life), Moscow, 1975.

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THE NATURE OF CHANGES IN SOME METABOLIC INDICES IN RESPONSE TO NONTHERMAL INTENSITY RADIOWAVES

Moscow GIGIYENA I SANITARIYA in Russian No 7, 1977, pp 34-38

[Article by N. K. Demokidova, USSR Academy of Medical Sciences Scientific Research Institute of Labor Hygiene and Occupational Diseases, Moscow]

[Text] According to clinical and experimental data (5,and others) electromagnetic fields (EMF) are capable of influencing neurosecretion of the hypothalamus and the endocrine system under its control which, as we know, plays an important role in metabolism and participates in protective-adaptive reactions of the body. We can hypothesize in this connection that disturbances in some metabolic indices of man and animals and changes in the weight of the latter in response to an EMF (2,4,9) are of neuroendocrine origin.

In this study we attempted to reveal the dependence between change in some indices of protein and water-salt metabolism in response to chronic exposure to ultrahigh and high frequency (UHF and HF respectively) EMF and the functions of endocrine glands such as the thyroid, the hypophysis, and the adrenal glands (this work is part of a series of experiments, the data of which were used to establish maximum permissible irradiation levels).*

The experiments were conducted on 96 adult male rats.

Inasmuch as quantitative and qualitative changes in diet elicit fluctuations in the level of basal metabolism, the control and experimental animals were maintained with a strictly identical dietary regimen. The rats were given only food pellets and water for 3 days before analysis of urine. Then they were placed in metabolic cages for a day, where they received only water. Daily diuresis, the concentration of total nitrogen (Conway's method), sodium and potassium (flame photometry method), or chlorides (Votochek's

*Data from clinical hygienic research by P. P. Fukalova, M. N. Sadchikova, and others.

method) in urine, and body weight (as an integral metabolic index) were determined. During the time of irradiation of the experimental rats, the control rats were kept in the same sort of cages made from plexiglass placed behind the wall of the generator room. The field intensity was measured with an IEMP-1 instrument.

To study the effect of UHF EMF we irradiated the animals 1 hour per day, daily for 3 months, at a field intensity of 150 v/m and a frequency of 69.7 MHz. Metabolic indices were determined for 24 rats (12 control and 12 experimental) after 2 weeks and 1,2, and 3 months of irradiation. At the end of the experiment these rats were killed to determine the weight of endocrine glands (in milligrams per 100 gm) and the indices of their functional state. Two other lots of animals consisting of 12 control and 12 experimental animals each were killed to study endocrine glands at other times (after 2 weeks and 1 month). Adrenal glands were fixed by means of (Romeys) method, and the thyroid was fixed in 4-percent formalin solution. The organs were embedded in paraffin and stained with hematoxylin-eosin. The surface areas of the cortical layer and the medulla of the adrenal glands was computed (6). Functional activity of the thyroid was assessed on the basis of its relative weight and one of the most sensitive morphometric indices of its activity--the height of the follicular epithelium (measurements were made on 25 folliculi from each median section of the gland).

The effect of HF EMF was studied with 24 rats (12 control and 12 experimental). These rats were irradiated for 4 hours daily at a field intensity of 70 v/m and a frequency of 14.8 MHz. The metabolic indices were checked once a month. Endocrine gland weights were determined after the animals were killed.

Metabolic changes were observed among animals subjected to UHF irradiation. Thus after 2 weeks of irradiation diuresis decreased somewhat and the Na/K coefficient decreased significantly (0.339±0.023 in control and 0.267±0.022 in experiment) which may indicate intensification of the mineralocorticoid function of the adrenal glands. The metabolic indices approached the control level after 1 month. By the end of the irradiation experiment we observed a sharp rise in elimination of water, nitrogen, and electrolytes, the sodium concentration in urine increasing by more than three times. This increase in metabolic indices attests to intensification of dissimilation processes, which is confirmed by appearance of a tendency for the weight of the animals to remain below that of control animals: Prior to irradiation, the weight of rats in the control and experimental group was identical (300±11.0 gm), while by the end of the experiment the weights were, correspondingly, 408±9.7 and 387±11.5 gm.

Comparing the shifts in metabolism with changes in the endocrine glands we can note that a correlation is observed between the variables in certain periods of time. Thus the sodium retention period coincided in time (2 weeks of irradiation) with a tendency toward greater weight of the adrenal gland and a significant rise in the area of their glomerular zone

(Table 1) which, as we know, produces mineralocorticoids having the capability for retaining sodium in the body (during this period of the experiment we observed an increase in the height of the follicular epithelium of the thyroid gland, which was an indication of an intensification in its function). The morphological indications of normalization of thyroid function observed after 1 month of irradiation (Table 2) were in correspondence with the equilibrium attained in metabolism.

Table 1. Effect of Irradiation By a UHF EMF on the Adrenal Glands.*

Группа (1)	Длительность облучения (2)	(3) Надпочечники: относительный вес, мг% (4)	(5) зоны и площадь коркового слоя, мм²: клубочковая (6)	пучковая (7)	сетчатая (8)
(9) Контрольная	—	16,6±0,73	0,82±0,02	3,60±0,25	2,84±0,15
(10) Опытная	2 нед (11)	17,7±0,81	0,96±0,04 $P<0{,}01$	3,46±0,20	2,96±0,23
(9) Контрольная	—	16,4±0,56	0,95±0,02	3,68±0,37	2,32±0,27
(10) Опытная	3 мес (12)	14,5±0,33 $P<0{,}01$	0,93±0,04	3,85±0,26	1,60±0,15 $P<0{,}05$

*P values are given only in the event of significant changes.

Key:

1. Group
2. Irradiation time
3. Adrenal glands
4. Relative weight, mg-%
5. Zones and surface area of the cortical layer, mm^2
6. Glomerular
7. Fascicular
8. Reticular
9. Control
10. Experimental
11. Weeks
12. Months

Table 2. Effect of Irradiation By a UHF EMF on the Weight of the Thyroid Gland and the Height of Its Follicular Epithelium.

Группа (1)	Длительность облучения (2)	Относительный вес железы. мг% (3)	(4) Высота эпителия фолликулов, мк
(5) Контрольная	—	7,7±0,32	8,05±0,039
(6) Опытная	2 нед (7)	7,7±0,27	9,60±0,27 $P<0{,}01$
(5) Контрольная	—	8,3±0,35	9,15±0,36
(6) Опытная	1 мес (8)	8,5±0,43	8,60±0,50
(5) Контрольная	—	6,8±0,27	9,90±0,74
(6) Опытная	3 мес (8)	6,3±0,30	12,30±0,74 $P<0{,}05$

Key:

1. Group
2. Irradiation time
3. Gland relative weight, mg-%
4. Height of follicular epithelium, μ
5. Control
6. Experimental
7. Weeks
8. Months

Table 3. Effect of Irradiation By a UHF EMF on the Area of the Adrenal Medulla.

Группа (1)	Длительность облучения (2)	Площадь мозгового вещества, мм² (3)
(4) Контрольная (5) Опытная	— 2 нед (6)	1,17±0,08 0,73±0,13 $P<0,01$
(4) Контрольная (5) Опытная	— 3 мес (7)	0,60±0,07 0,96±0.11 $P<0,02$

Key:

1. Group
2. Irradiation time
3. Medullar area, mm^2
4. Control
5. Experimental
6. Weeks
7. Months

Finally, the rise in excretion of nitrogen, water, and electrolytes which we observed after 3 months of irradiation coincided in time with indications of renewed activity of the thyroid gland, the hormones of which are capable of intensifying dissimilation processes, as we know (8). Apparently the function of the adrenal glands is diminished in this period, as is indicated by a decline in their weight, the decrease in area of the reticular zone, and the rise in sodium excretion.

In addition to the changes described above, after 1 month of irradiation we detected a significant increase in the weights of the hypophysis and the adrenal glands. Thus the mean relative weight of the hypophysis of animals in the control group was 2.60±0.04 gm, while that of experimental animals was 2.80±0.07 gm ($P<0.05$), while the weights of the adrenal glands were, correspondingly, 13.7±0.52 and 16.2±0.69 gm ($P<0.05$). We were unable to determine the morphological indices of adrenal function during this period; however, the rise in weight of these organs coupled with the increase in relative weight of the hypophysis might indicate increasing stimulation of their function by the hypothalamohypophyseal system, and it probably reflects the activity of higher nervous centers directed at restoring homeostasis (thyroid gland function and metabolic indices achieve a certain balance during this period).

We know that complex mutual relationships existing between the adrenal cortex and the thyroid gland (1) may sometimes assume a direct correlation (for example in early thyrotoxicosis and upon injection of thyroid hormones), and sometimes an inverse correlation (for example in the presence of Addison's disease). We observed similar phenomena in our experiments after 2 weeks of irradiation (at which time the mineralocorticoid function of the adrenal glands itensified and signs of activation of the thyroid gland appeared) and after 3 months of irradiation (when signs of a decline in adrenal function were noted and thyroid function increased at the same time).

Measurements of the area of the adrenal medulla indicated significant changes in this index--a decline after 2 weeks and a rise after 3 months of irradiation (Table 3). Judging from published data on the stimulatory effect of epinephrine, the hormone produced by the medulla, on the thyroid gland (15), the function of which intensified in our experiments precisely in these periods of irradiation, we can hypothesize that these phases reflect two different stages of stimulation of the medulla by central sympathetic nervous structures. These changes attest to activation of the sympathicoadrenal system which, as we know, is a necessary link in adaptive mechanisms.

Data from analysis of the biological action of an HF EMF indicate that the direction of its effect upon the analyzed indices is similar (although the degree to which the changes are pronounced and the times of their arisal are difficult to compare in view of the differences in field intensities and exposure times). Thus the decline in the concentration of chlorides in urine (as we know, this index indirectly reflects the sodium level) observed after 3 months of irradiation was superceded toward the end of the experiment by a pronounced rise in this concentration, coupled with a significant rise in excretion of other analyzed metabolites.

The lag of animal weight during this last period reaches its maximum, 54 gm on the average ($P<0.05$). An eosinopenic reaction (7) was observed in the first and second months of irradiation, indicating stimulation of the glucocorticoid function of the adrenal cortex. After 6 months of irradiation adrenal gland weight displayed a tendency toward growth, and it declined significantly toward the end of the experiment.

Thus the effectsof EMF of both ranges cause a rise in adrenocortical activity (enlargement of the weight of the adrenal glands, intensification of their mineralocorticoid and glucocorticoid functions), superceded by its decline toward the end of the experiment (reduction of the weight of the adrenal glands and of the area of their reticular zone, growth in excretion of sodium or chlorides). Such phasal changes in adrenocortical activity are a typical characteristic of body stress (1) which arises, as we know, on the background of heightened activity of the hypothalamus - hypophysis - adrenal cortex system (a rise in the activity of the hypothalamus in response to an EMF is evidenced in our experiments by the increase in the weight of the hypophysis and stimulation of the function of the adrenal cortex's glomerular zone, the only zone regulated directly by the hypothalamus, as is recognized by most authors).

According to recent data (13,14) in addition to the hypothalamus - hypophysis - adrenal cortex system a number of other systems are activated under the influence of various stressful effects, to include the sympathicoadrenal and hypothalamohypophyseal systems; signs of disturbance of the activity of these systems were noted in our experiments (changes in the area of the adrenal medulla and in the activity of the thyroid gland).

All of this allows the hypothesis that the shifts we revealed in metabolic indices in response to an EMF are a particular manifestation of protective-adaptive reactions. This is confirmed by published data. Thus Browne et al. (16) observed phasal changes in excretion of chlorides and water in response to various stress factors. I. V. Pavlova et al. (10) noted changes in the functional state of the sympathicoadrenal and the hypothalamohypophyseal-adrenal systems among patients suffering radiowave sickness, and they described some biochemical changes, including a decline in the concentration of chlorides in blood and its increase in urine.

We know that in addition to other changes, various stress factors are capable of eliciting a weight decrease in animals, which returns to normal in the stage of resistance (3). The failure of weight and other indices to normalize in our experiments can apparently be explained by the fact that the animals were incapable of achieving complete adaptation to EMF of the given intensities and exposure times.

Conclusions

1. Changes in diuresis and excretion of sodium, potassium, chlorides, and nitrogen with urine in response to HF and UHF EMF are probably mediated by the hormonal link of the adaptive mechanisms, and consequently they are a particular manifestation of the nonspecific stressful action of radiowaves.

2. The obtained data permit recommendation of this complex of metabolic indices in view of their informativeness and the convenience of determining them in clinical examination of persons chronically exposed to radio frequency electromagnetic fields.

BIBLIOGRAPHY

1. Viru, A. A. (editor), "Endokrinnyye mekhanizmy regulyatsii prisposobleniya organizma k myshechnoy deyatel'nosti" (Endocrine Mechanisms in Regulation of the Body's Adaptation to Muscular Activity), Vol 2, Tartu, 1971, pp 19-50.

2. Gordon, Z. V., "Voprosy gigiyeny truda i biologicheskogo deystviya elektromagnitnykh poley svertyvayushchikh chastot" (Problems in Labor Hygiene and the Biological Action of Superhigh Frequency Electromagnetic Fields), Moscow, 1966, p 59.

3. Gorizontov, P. D., et al., "Patologicheskaya fiziologiya ekstremal'nykh sostoyaniy" (Pathological Physiology of Extreme States), Moscow, 1973, p 11.

4. Demokidova, N. K., in "O biologicheskom deystvii elektromagnitnykh poley radiochastot" (The Biological Action of Radio Frequency Electromagnetic Fields), Issue 4, Moscow, 1973, pp 83-86, 165-168.

5. Zubkova-Mikhaylova, Ye. I., and Alekseyev, Yu. N., BYULL. EKSPER. BIOL., No 1, 1968, pp 115-118.

6. Kirillov, O. I., PROBL. ENDOKRINOL., No 1, 1973, pp 99-101.

7. Kitsovskaya, I. A., Fukalova, P. P., et al., in "O biologicheskom deystvii elektromagnitnykh poley radiochastot," Issue 4, Moscow, 1973, pp 115-118.

8. Leytes, S. M., and Lapteva, N. N., "Ocherki po patofiziologii obmena veshchestv i endokrinnoy sistemy" (Outlines of the Pathophysiology of Metabolism and the Endocrine System), Moscow, 1967, p 333.

9. Nikogosyan, S. V., in "O biologicheskom deystvii elektromagnitnykh poley radiochastot," Issue 3, Moscow, 1968, pp 107-111.

10. Pavlova, I. V., et al., GIG. TRUDA, No 3, 1970, pp 20-23.

11. Sadchikova, M. N., in "O biologicheskom deystvii elektromagnitnykh poley radiochastot," Issue 2, Moscow, 1964, pp 110-113.

12. Fukalova, P. P., in "O biologicheskom deystvii elektromagnitnykh poley radiochastot," Issue 2, Moscow, 1964, pp 244-248.

13. Furdui, F. L., et al., in "Stress i yego patogeneticheskiye mekhanizmy" (Stress and Its Pathogenic Mechanisms), Kishinev, 1973, pp 43-45.

14. Shreyberg, G. L., in "Fiziologiya i patofiziologiya gipotalamusa" (Physiology and Pathophysiology of the Hypothalamus), Moscow, 1966, pp 30-38.

15. Eskin, I. A., "Osnovy fiziologii endokrinnykh zhelez" (Fundamentals of Endocrine Gland Physiology), Moscow, 1968, p 89.

16. Browne, J. S. L., Karady, S., and Selye, H., J. PHYSIOL. (LOND.), Vol 97, 1939, pp 1-7.

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REDUCTION OF FUNCTIONAL CAPACITIES OF THE HEART UNDER CONDITIONS OF EFFECT OF ELECTROMAGNETIC FIELD OF INDUSTRIAL FREQUENCY ON THE BODY

Kiev VRACHEBNOYE DELO in Russian No 7, 1977 pp 141-143

/Article by Ye. V. Prokhvatilo, Kiev Scientific Research Institute of General and Communal Hygiene/

/Text/ The electromagnetic field of industrial frequency created by high-voltage electric transmission lines now acquires ever more pronounced hygienic significance among physical environmental factors. This is connected with the rapid development of electric power engineering at the present stage, which requires a steady rise in the carrying capacity and increase in the length of electric transmission lines. Right now the total length of the high-voltage lines of the power systems of the Ministry of Power and Electrification is on the order of 450,000 km.

At the same time, the problems concerning the possible biological effect of the electromagnetic field of industrial frequency of the intensities registered in the settlements located near lines have not been studied.

Investigations have established that the intensity of the electromagnetic field, depending on the intensity on the electric transmission line, as well as the distance from the extreme phase, can fluctuate within 100-16,000 v/m.

In the literature there are data attesting to the effect of the electromagnetic field of industrial frequency on the cardiovascular system. T. P. Asanova and coauthors (1963) describe bradycardia, the tendency to it and the lability of arterial pressure primarily toward hypotonia observed among workers of electric 400-500 kv substations. N. V. Revnova (1968) notes a disturbance in the rate and rhythm of cardiac activity and signs of muscular disorders of the heart on the basis of electrocardiographic data. As N. N. Goncharova and coauthors assume (1972), bradycardia and slowing of intracardiac conduction observed among workers servicing open distributing installations and electric transmission lines, along with general vascular dystonia, are of a nonspecific nature and are connected with disturbances in autonomic nervous regulation.

The noted changes in cardiac activity were observed among the personnel servicing electric transmission lines and substations at significant levels of intensity of the electromagnetic field (16 kv/m and higher).

This work was undertaken for the purpose of closely examining the ideas of the nature of changes in cardiac activity under the effect of a low-intensity electromagnetic field of industrial frequency, as well as studying the functional capacities of the heart under conditions of a physical load under the effect of the factor. In the experiment the bioelectric activity of the heart of rabbits was studied by the electrocardiographic method. Depending on the intensity (E) of the electromagnetic field where the animals were the latter were distributed in three groups (E=1,000, 500 and 100 v/m); the fourth served as control (E=0).

The electrocardiogram was recorded before the effect of an electromagnetic field (background) and during the period of effect after 15, 30, 45 and 60 days by means of the Elcar electrocardiograph in the second standard lead. Thin steel needles, which were inserted subcutaneously in the dorsal part of the extremities always in the same places, were used as electrodes.

An orthostatic test was chosen as the functional test. At the same time, the electrocardiogram was recorded while the animal was in a vertical position for 30 seconds.

The table proposed by L. F. Nurik (1971) was used in the decoding of electrocardiograms. The results obtained were processed statistically as compared with background indicators.

An analysis of the data obtained made it possible to disclose certain changes in the activity of the cardiovascular system of the animals located in an electromagnetic field of industrial frequency at E=1,000 v/m. In many respects these data agree with the observations of the above-mentioned authors. For example, we observed a slowing of the rhythm of cardiac activity, which increased in proportion to the effect of the electromagnetic field. Whereas the frequency of cardiac contractions before the effect was 291 beats per minute (296 beats per minute in control), after 30-60 days of effect it reliably dropped to 266 beats per minute (294 beats per minute in control).

With E=1,000 v/m a reduction was noted in the force of the contraction process of the auricles of the heart (reduction in the height of the P wave by one-half after a 60-day exposition; $P<0.01$) and of the ventricles (reduction in the voltage of the R wave from 0.38 to 0.20 mv; $P<0.001$).

The processes of repolarization of the ventricles, whose state is reflected by the T wave and the ST segment of the electrocardiogram, proved to be especially sensitive to the effect of the electromagnetic field. Thirty days after the exposition the T wave was much lower than the initial value (0.08 mv as compared to 0.10 mv; $P<0.01$). At the end of the period of effect it comprised 60 percent of the previous height, whereas among the intact animals throughout the experiment the voltage of the T wave fluctuated within 0.08-0.09 mv.

The changes in the height of the T wave were quite often accompanied by a change in its form (equilateral T with a sharpened top), as well as by a shift in the ST segment below an isoelectric line.

A disturbance in the correlation between the height of the waves of the electrocardiogram could be observed in a number of cases, which, perhaps, is connected with a change in the electric axis of the heart (A. O. Saytanov, 1960).

The use of an orthostatic test made it possible to reveal that under conditions of the effect of an unfavorable factor, which the electromagnetic field of industrial frequency is, the cardiovascular system of the body possesses much lower functional capacities than the cardiovascular system of an intact body not subjected to such an effect. For example, whereas the increase in the frequency of the pulse after a physical load among control animals was 22-32% and the reduction in the voltage of the P wave, 23%, the R wave, 14-29% and the T wave, 25-33%, among the animals in the electromagnetic field (E=1,000 v/m) these indicators fluctuated within 34-46%, 30%, 39-72% and 32-49% respectively.

A study of the time of conducting electric pulses from the auricles to the ventricles (PQ interval) and of the length of the electric systole at a given rhythm of cardiac activity (systolic indicator) did not reveal any significant changes in the conduction system of the heart even under conditions of a physical load. Throughout the experiment the length of the PQ interval among all the studied and control animals varied within 0.05-0.06 seconds, and the value of the systolic index, 73-82%.

The described changes in cardiac activity apply only to the animals in an electromagnetic field of an intensity of 1,000 v/m. With other intensities of the electromagnetic field (500 and 100 v/m) such changes were absent.

Thus, the electromagnetic field of industrial frequency is biologically active with regard to the cardiovascular system. Its effect is accompanied by a weakening of the force of the contraction process in the myocardium, which is especially clearly manifested against the background of the functional load and can be connected both with disturbances in electric phenomena (de- and repolarization) and with dystrophic processes and insufficiency of blood supply for the heart muscle.

Thus, the wide representation of the electromagnetic field of industrial frequency in the environment, as well as its biological activity, require a hygienic standardization of this factor. The data obtained can be used for substantiating the maximum permissible level of intensity of the electromagnetic field of industrial frequency for settlements.

BIBLIOGRAPHY

1. Asanova, T. P. et al., in the book "Materialy Nauchnoy Sessii Posvyashchennoy Itogam Raboty Instituta Gigiyeny Truda i Profzabolevaniy za 1961-1962" /Data of the Scientific Session Devoted to the Results of the Work of the Institute of Hygiene of Labor and Occupational Diseases in 1961-1962/, Leningrad, 1963.

2. Goncharova, N. N. et al., in the collection "Gigiyena Truda i Biologicheskoye Deystviye Elektromagnitnykh Voln Radiochastot" /Labor Hygiene and the Biological Effect of Electromagnetic Waves of Radio Frequencies/, Moscow, 1972, p 100.

3. Yershevich, V. V. et al., in the book "Dal'niye Elektroperedachi 750 kV" /Distant Electric Transmissions of 750 kv/. Part I. "Vozdushnyye Linii" /Air Lines/, Moscow, Energiya, 1974, p 21.

4. Nurik, L. F., FIZIOL. ZHURN. SSSR, 1971, Vol 57, No 6, p 912.

5. Revnova, N. V. et al., in the collection "Gigiyena Truda i Biologicheskoye Deystviye Elektromagnitnykh Voln Radiochastot," Moscow, 1968, p 132.

6. Saytanov, A. O., BYULL. EKSPERIM. BIOL. I MED., 1960, Vol 49, No 6, p 102.

11,439
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TECHNIQUE FOR DERIVING ELECTROGRAMS OF THE HEART OF THE INTACT FROG DURING EXPOSURE TO SUPERHIGH FREQUENCY FIELD

Yerevan BIOLOGICHESKIY ZHURNAL ARMENII in Russian No 7, 1977 pp 50-53

[Article by A. Sh. Pársadanyan, R. Z. Khafizov and R. E. Tigranyan, Institute of Biological Physics, USSR Academy of Sciences, submitted 11 Apr 77]

[Text] This article describes the technique for derivation of bioelectric activity of the intact frog, without traumatizing the heart, during exposure to a pulsed superhigh frequency field. The authors discuss the existing methods of derivation, from the standpoint of their applicability under such conditions. They describe electrodes free of artifacts. They submit the results of using this technique in strong pulsed superhigh frequency fields and a sample of a tracing.

In recent times, increasing attention is being given to the effects of interaction between an SHF [superhigh frequency] electromagnetic field and biological systems. In spite of the many studies pursued in this field and theoretical theses [1], there are still "gaps." Thus, it is still not known how the intact organism reacts when exposed to an electromagnetic field. Is there summation of different changes occurring as a result of the effects of the field on various local levels of a complex biological system, ultimately eliciting a perceptible effect or, on the contrary, does the system as a whole attenuate local effects including [or by triggering] defense mechanisms? We cannot rule out that both phenomena occur simultaneously, with some prevalence of one over the other. There are some data in the literature dealing with the effects of SHF fields on the heart of various animals [2-4]. A comparison of the results of these studies to data obtained on an intact organism could, to some extent, demonstrate the function of defense resources of the organism, furnish a quantitative estimate of extent of development of a particular effect, etc.

We selected the lake frog as the object of our investigation. Analysis of the literature revealed that most electrophysiological studies of the heart of amphibians (frogs) were pursued with the chest open [5, 6].

Samoylov conducted the first comprehensive studies of the frog EKG [5]. Experiments were conducted on frogs with an open chest, using tubular electrodes filled with saline (NaCl). The active electrode was attached to the apex of the ventricle with a thread ligature. Analysis of various forms of EKG led the author to the conclusion that they are the result of superposition of diverse tracings. It was shown that the R wave was always the largest and stable on the EKG. The T wave was quite variable and random, both in shape and polarity. This method of derivation made it possible to record EKG's with amplitudes of the order of 20 mV.

Vorontsov [7] studied the frog electrocardiogram by means of an active electrode consisting of a glass cannula, the thin end of which was filled with gelatin in Ringers' solution; a saturated solution of zinc sulfate was poured in the wider part, and a zinc rod was immersed in it. One of these electrodes was inserted in the ventricle of the frog's heart, while the other was gradually moved from the apex of the ventricle to the atria. The electrogram recorded in this manner changed constantly. Thus, the size of the waves on the electrogram, their polarity, as well as the presence of some of them were unrelated to some inner properties of the myocardium or processes in it, but to the position of active electrodes on the heart. Comparing the human EKG to the electrograms of the frog heart, the author indicates that the tracings are the same.

There is also considerable reference information on bioelectric activity of the heart in the book by Roshchevskiy [8].

Subsequent studies of the frog EKG, dealing with specific questions, for example, seasonal temperature influence on cardiac activity, factors affecting recovery from bradycardia and others were conducted using active electrodes made of metal (copper, stainless steel, silver) and consisting of needles inserted in the chest, in the region of the heart [9, 10].

Such electrodes were also used to study the biological effects of SHF fields.

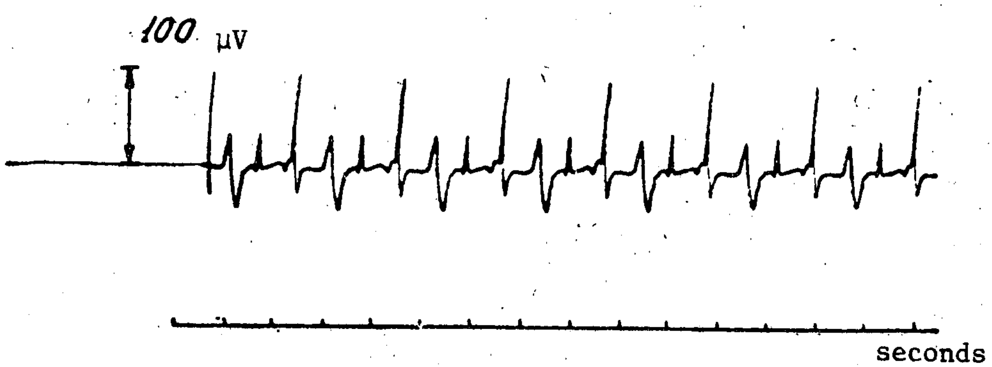
In 1966, Levitina [11] conducted experiments to test the nonthermal effects of microwaves on the forg's heart rate. The heart rate was recorded by means of needle electrodes. The experimental results revealed that exposure of the dorsal aspect of the body to nonthermal microwaves leads to a negative (slowing) chronotropic effect, while exposure of the ventral aspect, to a positive (faster rhythm) chronotropic effect.

Similar experiments were conducted on the isolated frog heart by Frey [4]. A coaxial electrode system, which he proposed [12], was used to derive the electrocardiogram.

However, when metal conductors are put in an SHF field, current is induced in them and, being detected in the input circuits of the recording devices, it can induce subliminal stimulation of the object as well as distortions in the tracing of the electric signal. Alignment of the active metal electrodes in the SHF field lowers the magnitude of induced current; however, this does not completely rule out the possibility of an artifact and causes perceptible distortions in the appearance of the field and thus precludes correct performance of the experiment. For this reason, of the methods listed above, one should rule out those in which metal electrodes are used to record bioelectric activity of the heart.

Moreover, opening the chest, application of ligatures and insertion of tubular probes directly in the heart are rough procedures and, although we failed to find information in the literature concerning the extent of change in cardiac activity as a result of such manipulations, we believe it would be desirable to avoid direct trauma to the heart. This would bring us as close as possible to normal conditions of cardiac function in the intact organism.

For this reason, we used the following technique: We removed about 1 cm^2 of skin from the chest, in the region of the heart. We placed two artifact-free liquid electrodes [13], consisting of elongated glass tubes with tip diameter of 100-200 μm over the exposed region. The other end of the electrodes was connected to silicone rubber tubes. Beyond the irradiation zone, the rubber tubes were placed in a metal shield. The tips of the rubber tubes were connected to plastic dishes equipped with rubber bulbs. Silver electrodes were put in the same dishes. The entire system was filled with Ringer's solution by means of bulbs. Thus, the liquid-metal contact was removed from the zone of irradiation. The object was irradiated in a square-wave waveguide (270×150, TE_{10} wave). The segment of silicone tubes contained in metal attenuates the SHF field about 1000-fold (30 dB) per running centimeter and, in essence, is a low-frequency filter [13]. In other words, the relatively high resistance of such electrodes (tens of kΩ) virtually fails to distort the SHF field, suppresses any possible high-frequency inductions and makes it possible to transmit the signal from the object to the recording equipment with little loss. The great advantage of this electrode system is that there is no need for adjustment [alignment] in the irradiation zone. The derived electric potential of the heart is recorded on an electroencephalograph. The amplitude of the R wave constituted 150±50 μV as the mean for a series of 50 objects. No induced current or signal distortion, as compared to the control, were demonstrable with exposure of objects of SHF fields with up to 100 V pulses. The shape of the recorded electrogram is identical to that illustrated in photographs in the cited literature. Below is a photograph of an electrographic tracing of the heart of an intact frog.



Electrocardiogram of intact frog

The results of this study warrant the belief that the proposed method of preparing the object rules out trauma to the heart and provides for normal functioning of the object for several hours; the used derivation system, using artifact-free liquid electrodes provides for stable recording of electrograms of the heart of an intact frog for at least 2 h; the artifact-free liquid electrodes rule out completely the possibility of high-frequency induced current and provide for distinct recording of the useful signal.

BIBLIOGRAPHY

1. Presman, A. S. "Electromagnetic Fields and Living Nature," Moscow, 1968.

2. Presman, A. S., and Levitina, N. A. BYULL. EKSPER. BIOL. I MED. [Bulletin of Experimental Biology and Medicine], 1, 41, 1962.

3. Idem, Ibid, 2, 39, 1962.

4. Frey, A. H. LIFE SCIENCES 7(2), 505-512, 1968.

5. Samoiloff, A. PFLUGER'S ARCHIV., 135, 417-468, 1910.

6. Schaefer, H. J. ELECTROPHYSIOLOGIE, Vienna, Vol 2, 1942.

7. Vorontsov, D. S. "General Electrophysiology," Moscow, 1961.

8. Roshchevskiy, M. P. "Evolutionary Electrocardiology," Leningrad, 1972.

9. Jones, D. R. J. EXP. BIOL., 44, 397-411, 1966.

10. Lung, G. F., and Dingle, J. Ibid, 48, 265-270, 1968.

11. Levitina, N. A. BYULL. EKSPER. BIOL. I MED., 12, 64, 1966.

12. Frey, A. H "U.S.A. Patent 3.540.434. cl. 128/2.1," 1970.

13. Tyazhelov, V. V.; Tigranian, R. E.; and Khizniak, E. P. THE JOURNAL OF MICROWAVE POWER, 12, 2, 618-626, 1977.

10,657
CSO: 1870

UDC: 616-005.5-092-02:615.849.11

EFFECTS OF UHF MAGNETIC FIELDS ON DEVELOPMENT OF ARTERIAL AND LYMPHATIC COLLATERALS (AN EXPERIMENTAL STUDY)

Moscow VOPROSY KURORTOLOGII, FIZIOTERAPII I LECHEBNOY FIZICHESKOY KUL'TURY in Russian No 4, 1977 pp 65-68

[Article by Armando Hidalgo Pas, Chair of Normal Anatomy (headed by Prof M. G. Prives), First Leningrad Medical Institute imeni Academician A. P. Pavlov, submitted 19 Oct 76]

[Text] A. V. Drozdova, Yu. A. Kulikov and F. N. Ibragimov, and R. I. Khudayberdyyev studied the effects of UHF [ultrahigh-frequency] electric fields on development of arterial and lymphatic collaterals. However, we could not find any works in the available literature concerned with morphological investigation of the effects of UHF magnetic fields on the development of arterial and lymphatic collaterals.

Our objective here was to investigate the effects of UHF magnetic fields on the rate and nature of development of arterial and lymphatic collaterals in the hind limbs of rats.

> We used a portable UHF-30 machine with an EVT-1 resonance inductor in our experiments. Using this inductor, we exposed tissues predominantly to an UHF magnetic field. Some authors now call this method of treatment UHF inductothermy (L. A. Skurikhina; V. N. Saperov and A. N. Sheina).

Our study was conducted on 248 albino rats. We studied the arterial and lymphatic stream under normal conditions in 20 of them. Then, pilot experiments were conducted on 12 rats to demonstrate conditions of exposure to an UHF magnetic field that would not destroy changes in tissues of the hind legs. The other 216 rats were divided into 6 groups.

> The first two groups were controls: we studied formation of arterial collaterals following bilateral section of the femoral artery (1st group) and development of peripheral lymphatic pathways after bilateral extirpation of the popliteal lymph nodes (2d group) without exposure to UHF magnetic field.

In the 3d and 4th groups, we investigated development of arterial collaterals under the influence of 15 and 30 W UHF magnetic fields and in the 5th and 6th, the dynamics of development of lymphatic collateral pathways under the influence of the same UHF magnetic fields. After 3-4 days, the operated limbs of experimental groups of animals (5th and 6th) were exposed to the factor in question; follow-up of development of collaterals was pursued for 2, 4, 6, 8, 10 and 16 weeks after surgery and exposure to the UHF magnetic field.

We used the following investigative techniques: 1) arteriography and lymphography followed by preparation; 2) injection of an India ink and gelatin mass into the arterial stream, preparation of sections of femoral muscles and clearing thereof by the method of A. M. Malygin; measurement of diameter of intramuscular blood vessels by the photometric method (A. V. Borisov); 3) preparation of transverse serial sections of arterial collaterals, staining of sections and calculation of transverse section of the tunica media of these arteries according to G. S. Katinas.

Exploratory Experiments: The pelvic extremities of unoperated animals were exposed to 15 and 30 W UHF magnetic fields for 20, 15 and 10 min daily, for 10 days. Exposure for 15 and 20 min led to destruction of tissues and stasis in the limbs. The lack of pathomorphological changes after exposure for 10 min warranted the belief that these conditions are suitable for subsequent experiments.

Development of Arterial Collaterals Without Exposure to UHF Magnetic Field (First Group of Animals--Control)

On the basis of the results of arteriography and subsequent preparation, we demonstrated that five zones of collaterals of hind limbs can be distinguished in rats: 1) cranial, in the muscles of the ventrolateral wall of the abdomen; 2) posterior, deep in the posterior group of femoral muscles; 3) anterior, in the muscles of the anterior femoral group; 4) medial, long; 5) medial, short--in muscles of the medial femoral group.*

The dynamics of formation of arterial collaterals are as follows: at the early postoperative stages (after 2 weeks), there is development of long collateral arteries in the 1st and 2d zones; 4-6 weeks later, along with the previously developed collaterals, there are some in the 3d, 4th and 5th zones; there is gradual increase thereafter (up to 10 weeks) in diameter of the collaterals; no more changes are demonstrable in the collateral system in the interval from the 10th to 16th week.

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*R. A. Bardina distinguished such zones after extirpation of the dog's femoral artery.

Development of Arterial Collaterals After Exposure to UHF Magnetic Field (Third and Fourth Groups of Animals)

The results of arteriography and subsequent preparation revealed that there is development of arterial collaterals in all zones, in the 2d postoperative week, after exposure to 15 and 30 W UHF magnetic fields. Consequently, there is faster development of collateral arteries, as compared to the control. It must be noted that the collaterals are finer and less tortuous after exposure to 30 W UHF magnetic field than after exposure to a 15-W field.

After 4-6-8 weeks, the diameter of the collaterals after exposure to 15 W UHF magnetic fields was greater than in the 1st and 2d groups of animals. Moreover, 8 weeks after exposure to 15 W UHF magnetic field, we observed development of 3 collateral vessels in the 4th zone, whereas after exposure to a 30 W field, there were only 2 collateral vessels in the 4th zone, as in control rats.

There was a negligible difference between experimental and control rats, with regard to arterial collaterals of the hind limbs after 10 weeks.

After 16 weeks, the arterial systems of the limbs of experimental rats, after exposure to 15 and 30 W UHF magnetic fields, were about the same as in control animals.

In the course of development of collaterals, there was more distinct dilatation of intramuscular blood vessels and a greater number thereof following exposure to the UHF magnetic field, as compared to the control; the capacity of the intraorganic vascular system and cross section of the tunica media of collateral arteries were also larger in the experimental animals.

These indices were higher in experimental rats exposed to 15 W UHF magnetic field than in the 1st and 2d groups of animals, and particularly after 2-6 weeks.

The obtained data indicate that exposure to a 15 W UHF magnetic field has a more marked and stable effect on development of arterial collaterals than a 30 W field. It should be assumed that the nervous system plays a part in occurrence of these morphological changes in the arterial system, in the course of development of collaterals under the influence of UHF magnetic fields. Evidently, the vascular reaction is in the nature of vasodilatation as a result of stimulation of receptors by the UHF magnetic field.

Results of Investigation of the Lymphatic System in the Control and After Exposure to UHF Magnetic Field (Second, Fifth and Sixth Groups of Animals)

In most rats, the main pathway for efflux of lymph from the leg and thigh is restored 2 weeks after resection of popliteal lymph nodes due to development of anastomosis between the stumps of the severed vessels. Thereafter (4-6-8-10-16 weeks), efflux of lymph takes place only through the main pathway, and the lymphatic plexi and collaterals are not filled.

Two weeks after the operation, a plexus of subcutaneous lymphatic vessels is demonstrable under the influence of exposure to 15 and 30 W UHF magnetic fields. Efflux of lymph takes place only via the superficial vessels toward the inguinal node and then along the superficial lateral lymphatic pathway to the axillary node. These nodes are not regional ones for efflux of lymph from the region of the food. Such efflux could be attributed to dilatation of superficial lymphatic vessels of the rat limbs, as a result of multiple exposure to oscillations of the UHF magnetic field. Most of the lymph flowed expressly via these dilated superficial lymphatic vessels to nodes that are not regional.

As a rule, there was efflux of lymph via both the superficial pathway to inguinal lymph nodes and the main deep pathway to the iliac nodes 4, 6, 8 and 10 weeks after surgery and exposure to 15 and 30 W UHF magnetic fields.

There was also efflux of lymph in two directions, in superficial and deep vessels, after 16 weeks, under the influence of 15W UHF magnetic field. At this same time, with exposure to 30 W UHF magnetic field, it occurred in all rats only via the main deep pathway and no collateral pathways were demonstrable. This difference is probably attributable to more prolonged dilatation of superficial lymphatic vessels under the influence of the 15 W UHF magnetic field.

Since there is a single vascular system, and the lymphatic system, like the blood system, has the capacity of forming collaterals, the vasodilating effect of the UHF magnetic field (as can be seen from the results we obtained with the 3d and 4th groups) should apparently also cause dilatation of collateral lymphatic vessels.

Conclusions

1. A series of exposures to an UHF magnetic field accelerates development of arterial collaterals and improves their structure.

2. The changes in the collateral system are the most marked with exposure to a 15 W UHF magnetic field, and they are less marked under the influence of a 30 W field.

3. A series of exposures to an UHF magnetic field aids in efflux of lymph via collateral and reserve lymphatic vessels.

4. Exposure to a 15 W field has a more marked and longer effect on efflux of lymph via superficial pathways than a 30 W UHF magnetic field.

BIBLIOGRAPHY

1. Bardina, R. A. TRUDY SARATOVSKOGO MED. IN-TA [Works of Saratov Medical Institute], Vol 50 1966, pp 89-91.

2. Borisov, A. V. "Intraorganic Lymphatic Capillaries and Peritoneal Vessels of Man," author abstract of doctoral dissertation, Leningrad, 1967.

3. Drozdova, A. V. in "Voprosy anatomii i operativnoy khirurgii" [Problems of Anatomy and Operative Surgery], Leningrad, Vyp 1, 1955, pp 229-237.

4. Katinas, G. S. ARKH. ANAT. [Archives of Anatomy], No 8, 1963, pp 67-74.

5. Kulikov, Yu. A., and Igragimov, F. N. in "Tezisy 8-go Vsesoyuznogo s"yezda anatomov, gistologov i embriologov" [Summaries of Papers Delivered at the 8th All-Union Congress of Anatomists, Histologists and Embryologists], Tashkent, 1974, pp 213-214.

6. Malygin, A. M. AZERBAYDZHANSK. MED. ZH. [Azerbaydzhan Medical Journal], No 6, 1956, pp 75-77.

7. Skurikhina, L. A. in "Prakticheskoye rukovodstvo po provedeniyu fizioterapevticheskikh protsedur" [Practical Manual on Administration of Physiotherapy], edited by A. N. Obrosov, Moscow, 1970, pp 99-118.

8. Khudayberdyyev, R. I. in "Teziy 8-go Vsesoyuznogo s"yezda anatomov, gistologov i embriologov," Tashkent, 1974, pp 402-403.

10,657
CSO: 1870

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